A Comparison of simulations of Rossby Wave Breaking with Icosahedral and Lon-Lat Models

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Outline

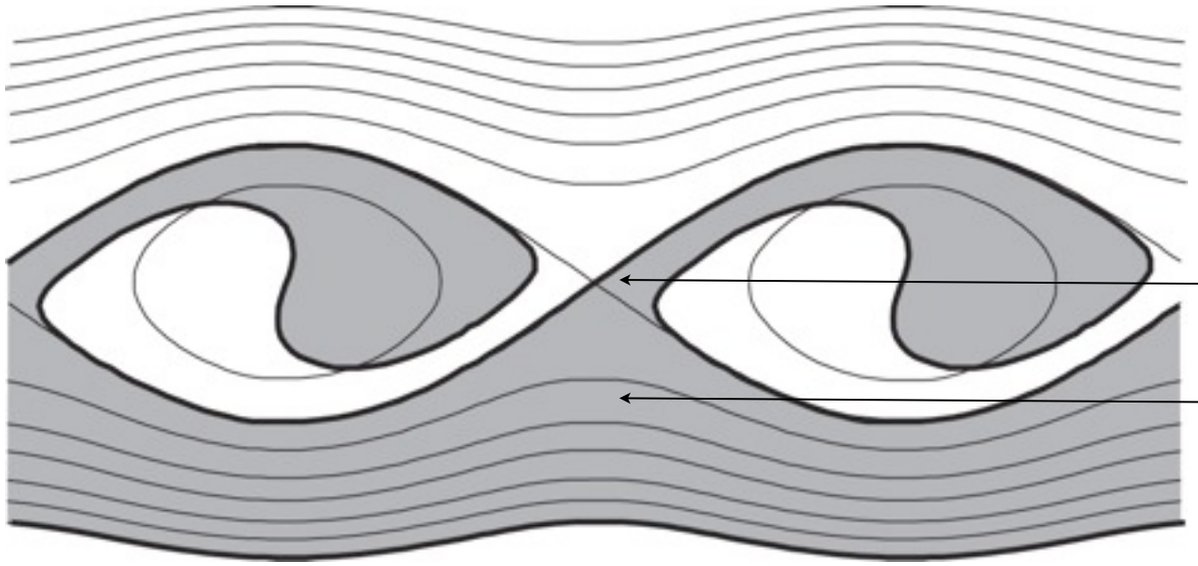
- A brief introduction of Rossby wave breaking (RWB) at critical layers (or latitudes)
- Shallow-water models used in this comparison
- Comparison of results
- Icosahedral and Lon-Lat barotropic models

Rossby Wave Breaking (RWB) in the context of critical layers (latitudes) and Lagrangian transport

An important mechanism for horizontal Stratospheric mixing in the Southern Hemisphere

Critical latitudes are places where U – *c* = 0

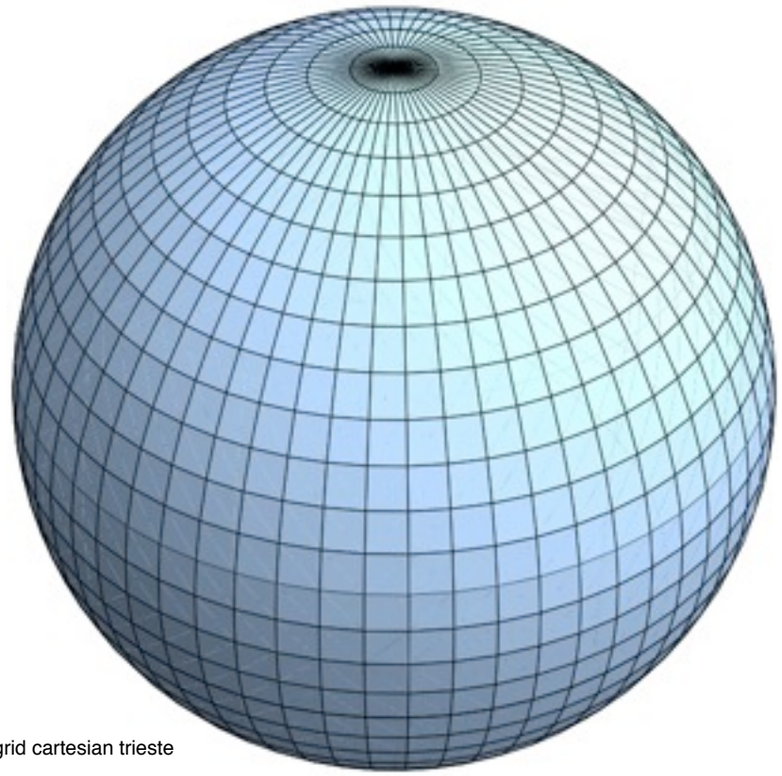
"Cat's eye" structure at the *critical* latitude and Rossby-wave breaking and Lagrangian transport



De La Camara et al. (JAS, 2013)

Selected grids used in global models

Lon-Lat grid (Cartesian)



grid cartesian trieste

Quadrilateral cells

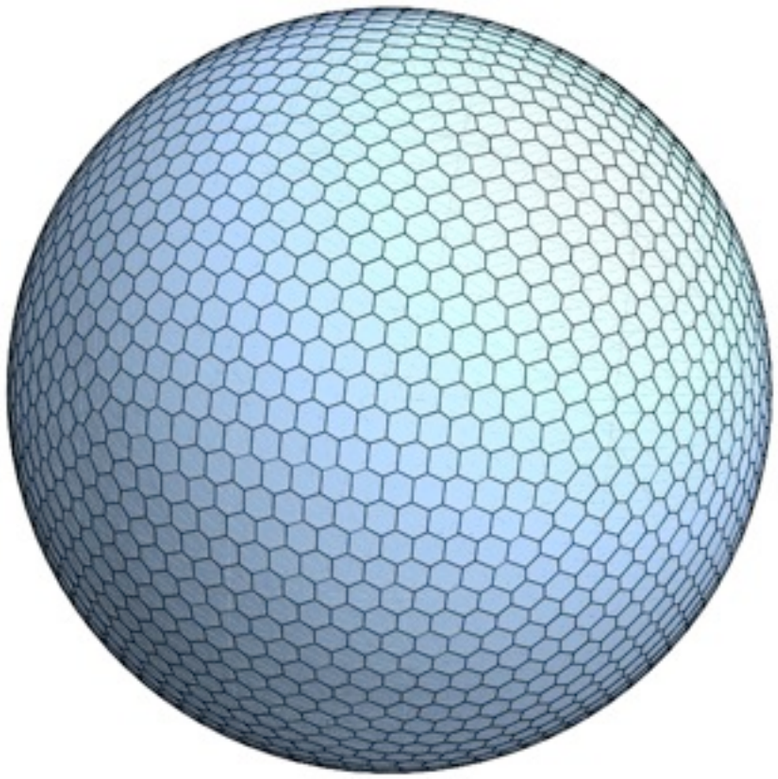
Poor isotropy

Poor uniformity

Pole problem

Vector Velocity and
FV dycores
No Z-grid dycore

Hexagon-Pentagon Icosahedral



Hexagonal and pentagonal cells

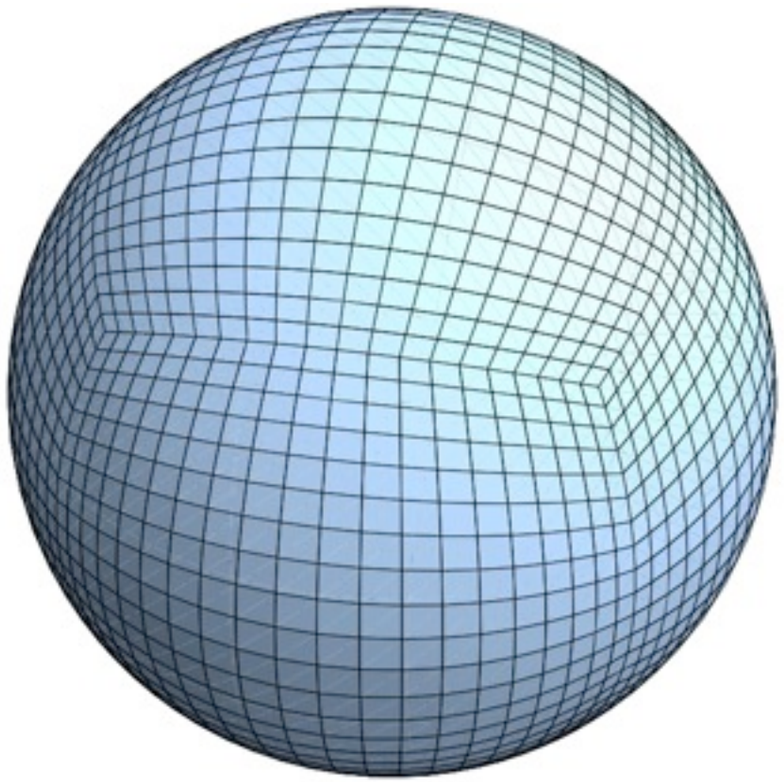
Excellent isotropy

Excellent uniformity

Pentagon problem

Vector Velocity dycores
Z-grid dycore

Cubed Sphere



Quadrilateral cells

Poor isotropy

Acceptable uniformity

Corner problem

Vector Velocity dycores
SE and FV dycores
No Z-grid dycore

Not discussed here

Shallow-water models

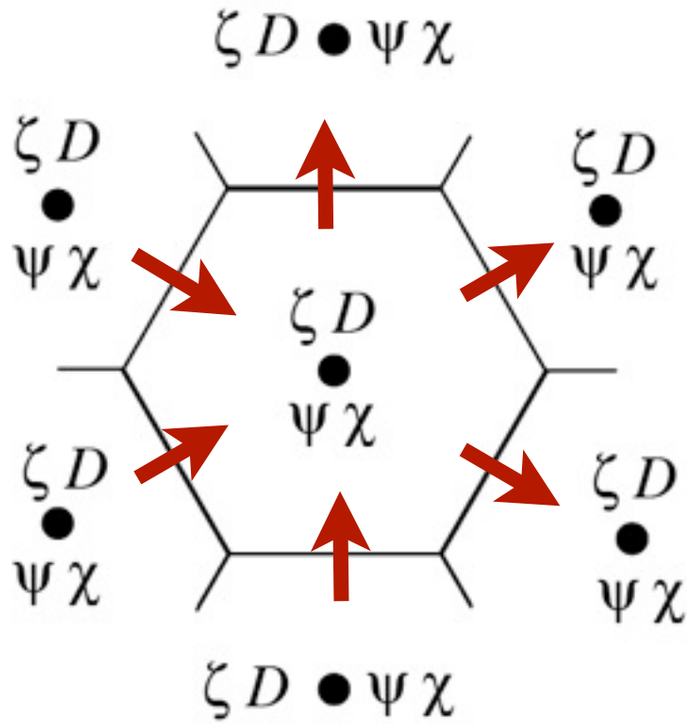
1) Icosahedral (Z-grid) model

- Shallow-water version of CSU's global icosahedral grid model (Heikes and Randall, 1995; Heikes et al., 2013)

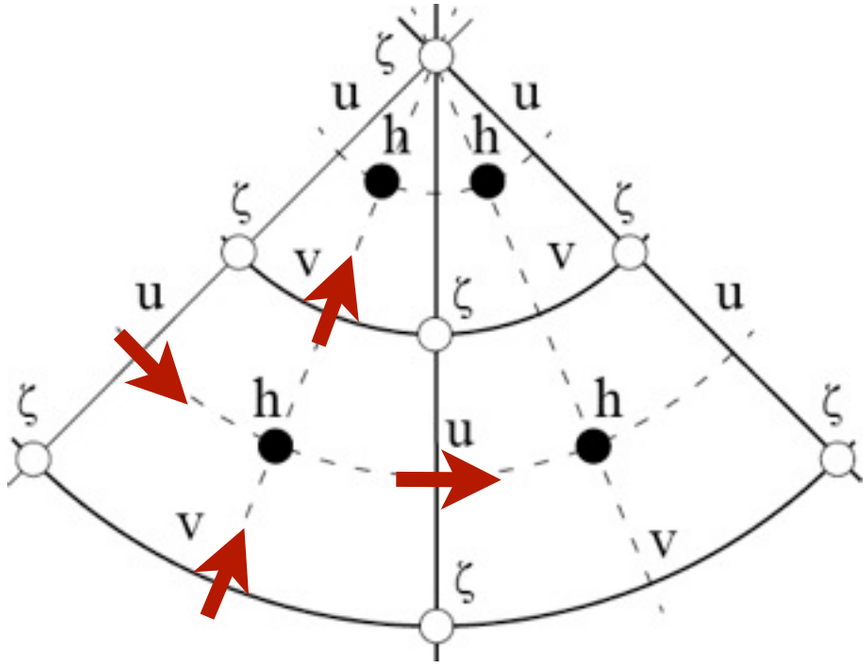
2) Lon-Lat (C-grid) model

- Shallow-water version of the global isentropic model (Jung et al. 2001)
  - **SAH:** a second-order scheme (Sadourny, 1975; Arakawa and Hsu, 1990)
  - **AL:** a second-order scheme (Arakawa and Lamb, 1981)
  - **ST:** a fourth-order scheme (Suarez and Takacs, 1994)
  - **TW:** a fourth-order scheme (Takano and Wurtele, 1983)

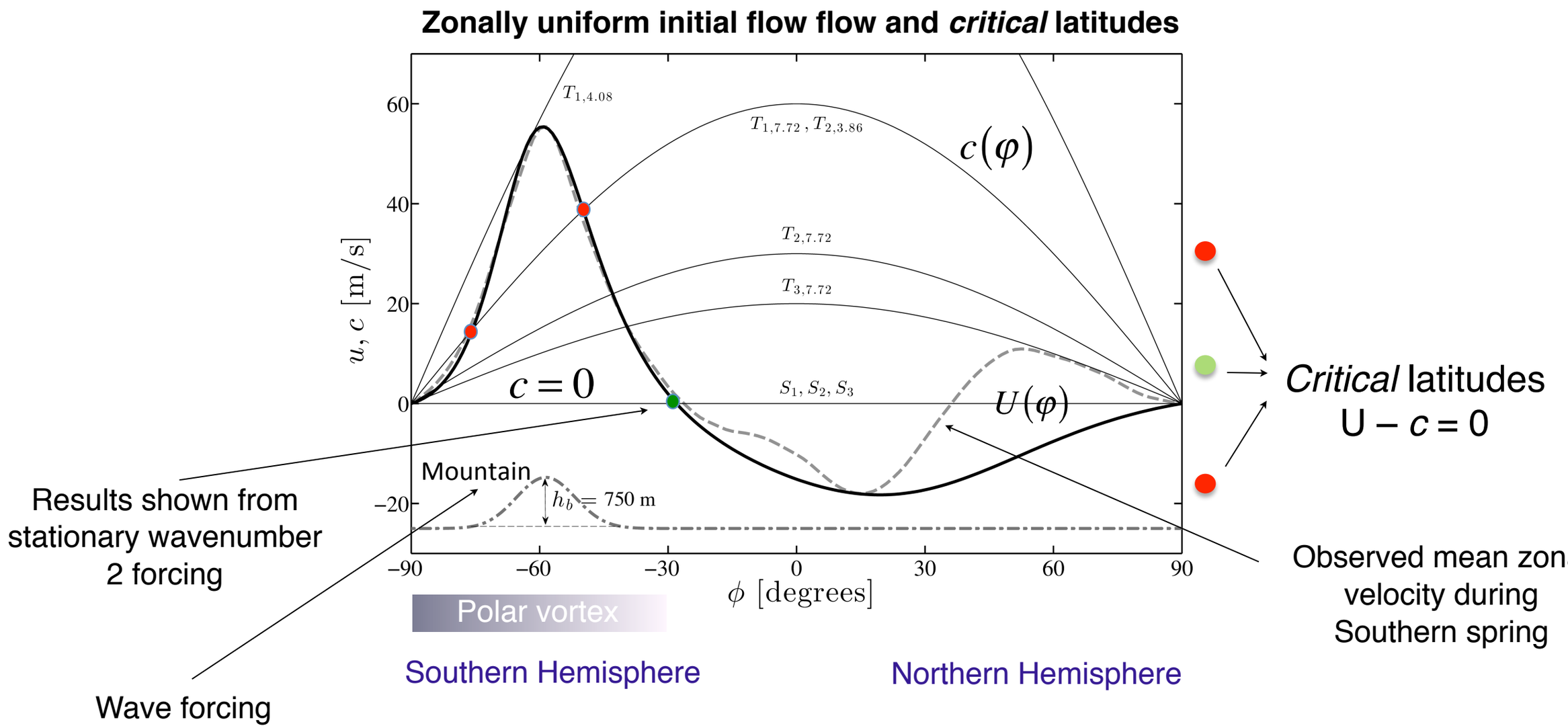
Icosahedral Z-grid



Lon-lat (Cartesian) C-grid



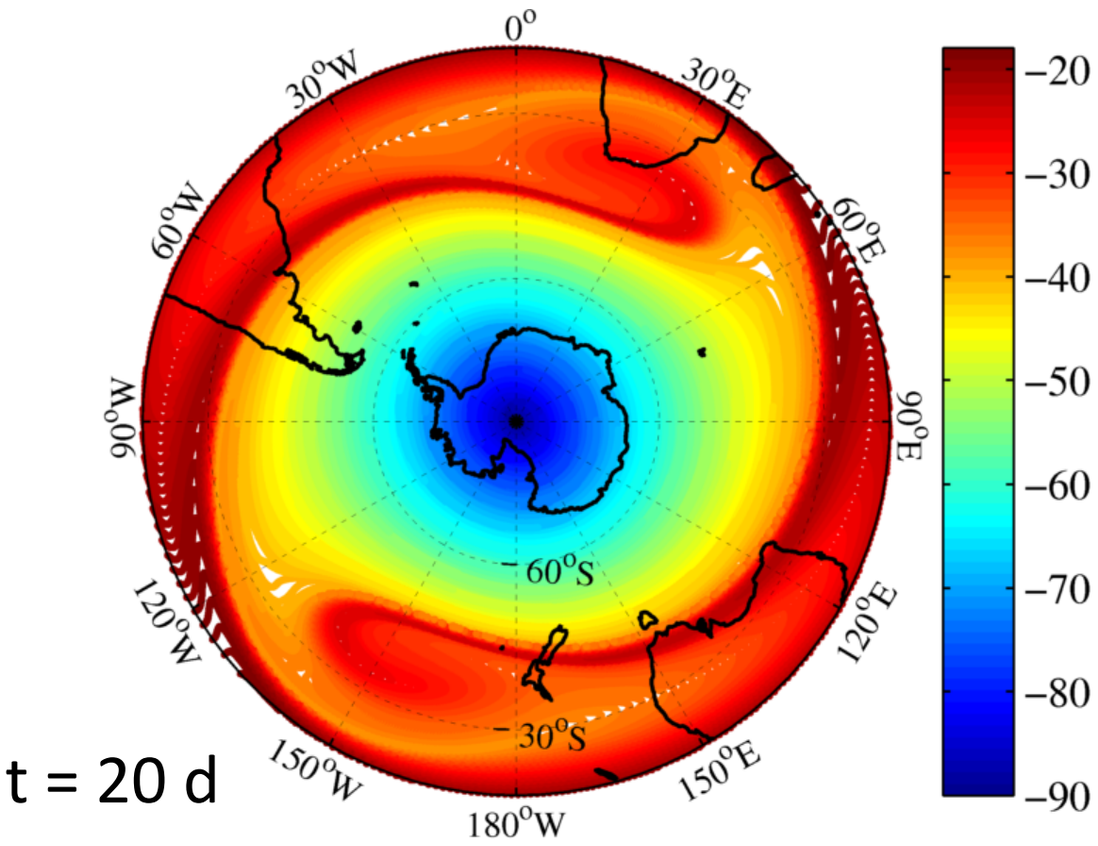
Simulations of RWB during Southern spring with the icosahedral and lon-lat shallow-water models

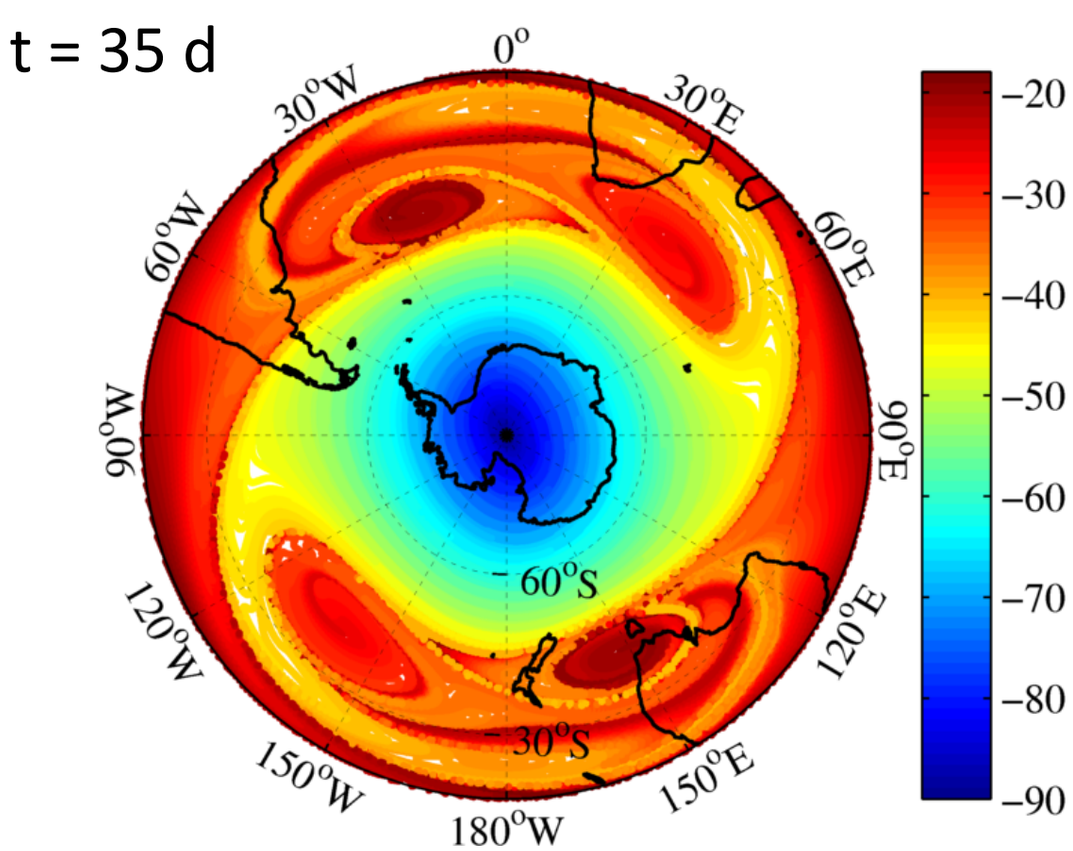


Guha and Mechoso (AMS, 2015)

Trajectories

Icosahedral model run with the stationary wavenumber-2 forcing





Resolution: G6 (grid distance is approx. 120 km)

Guha and Mechoso (AMS, 2015)

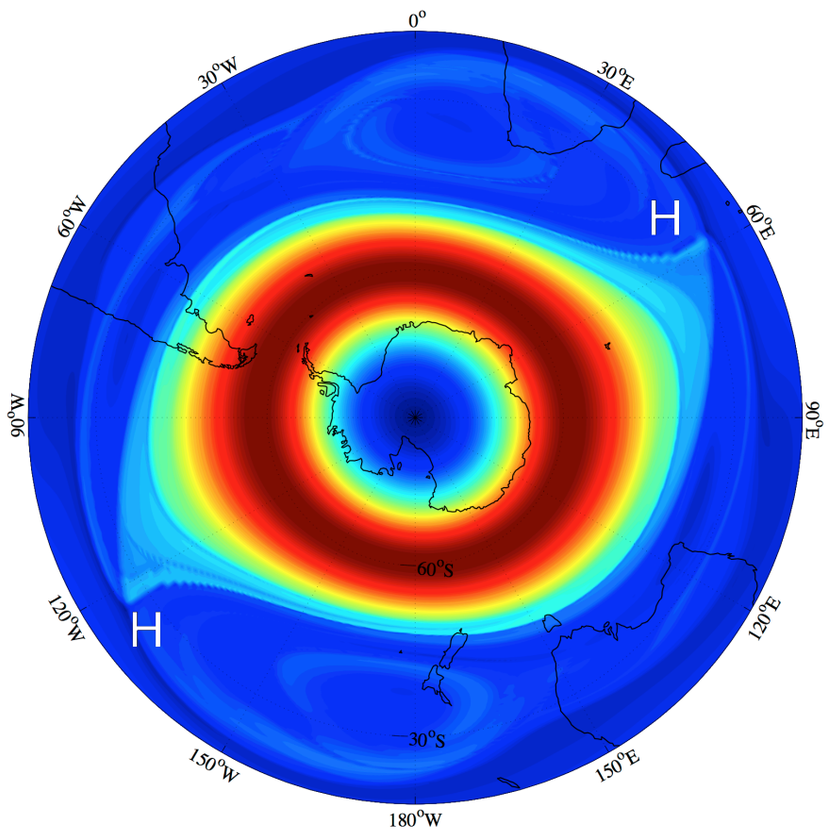
Hyperbolic points defined by Lagrangian descriptor "M"

$$M_\tau\left(x_0, y_0, z_0, t_0\right) \equiv \int_{t_0-\tau}^{t_0+\tau} \sqrt{\dot{x}^2 + \dot{y}^2 + \dot{z}^2}\, dt$$

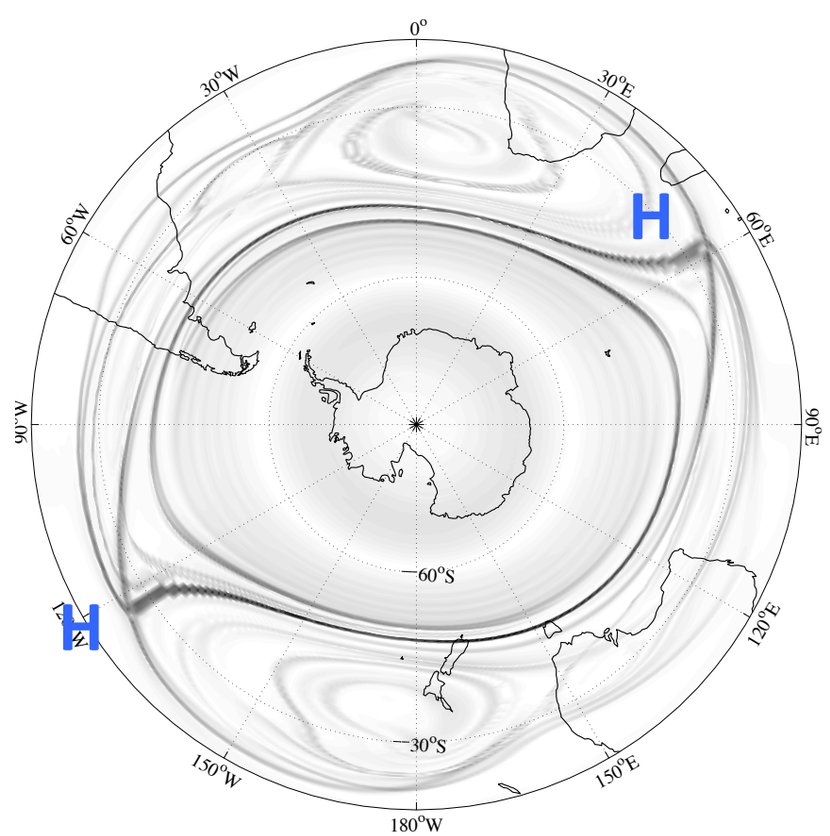
De La Camara et al. (JAS, 2013)

Icosahedral model results for t_0=25 days and τ=20 days

M



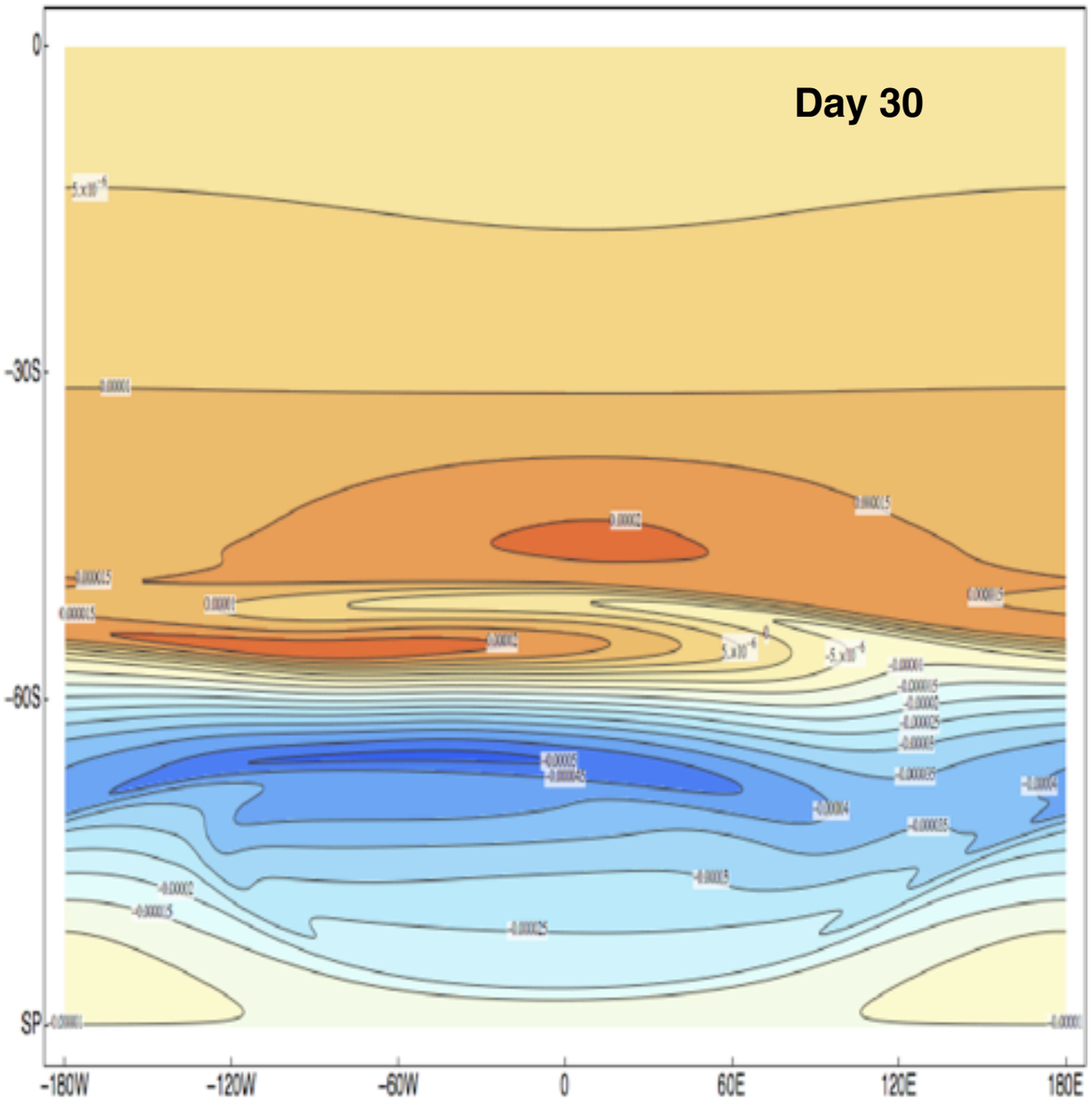
$|\nabla M|$



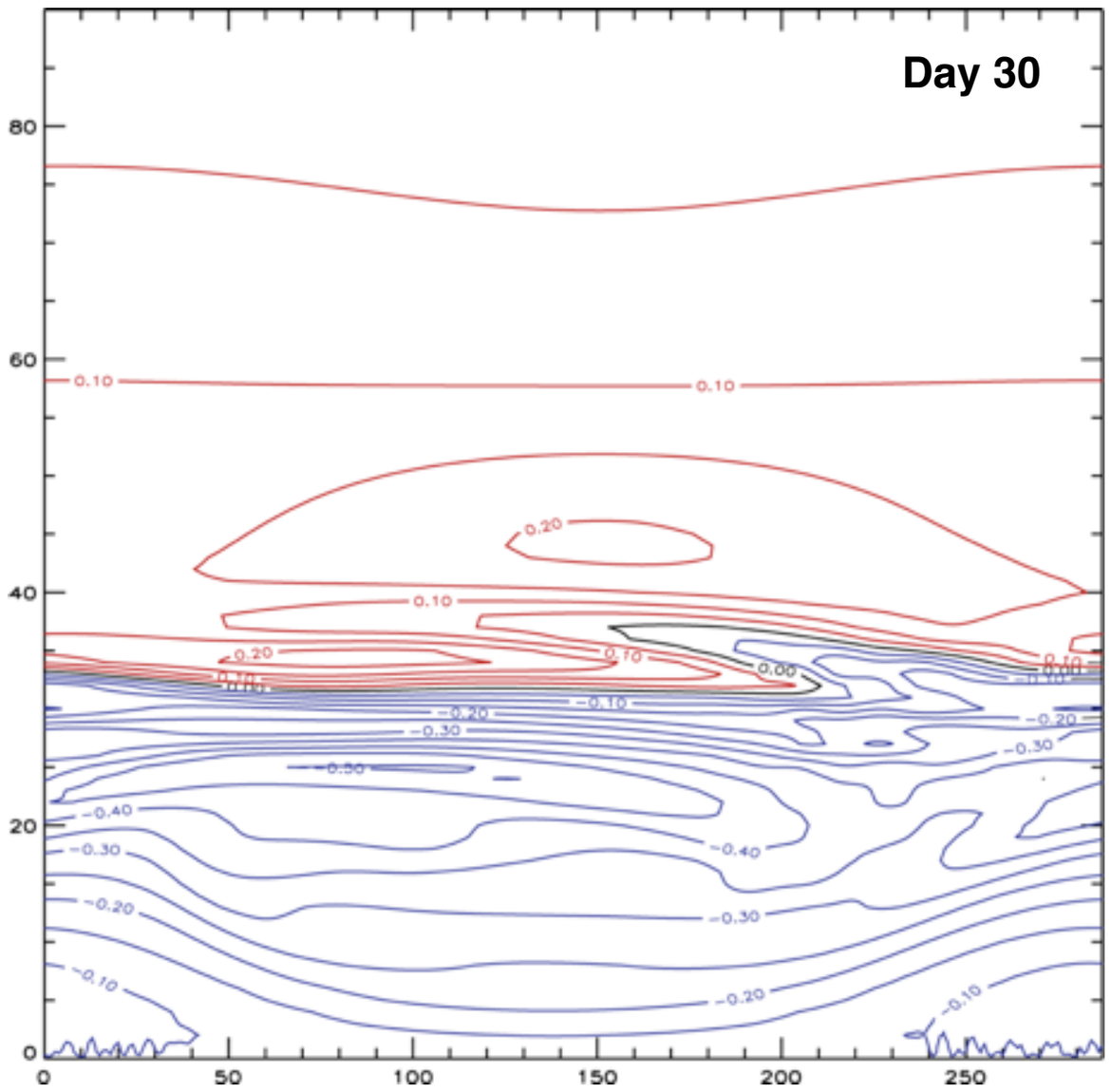
Guha and Mechoso (AMS, 2015)

Relative vorticity in an RWB episode (Day 30)

Icosahedral model



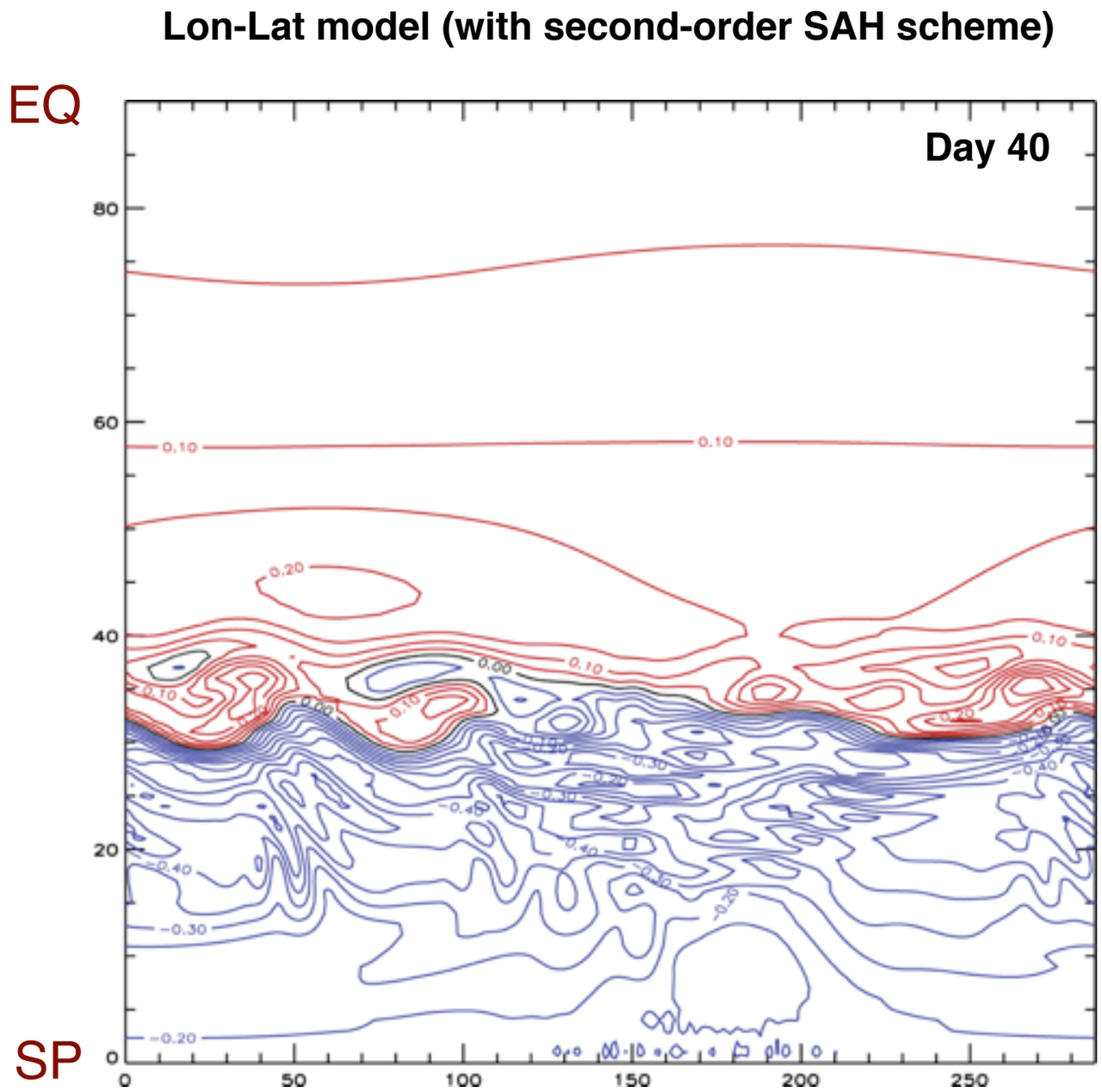
Lon-Lat model (with second-order SAH scheme)



Icosahedral model resolution: G8 (grid distance is approx. 30 km)

Lon-Lat model resolution: 1ºX1.25º (grid distance is approx. 100 km)
Time step: 2 secs

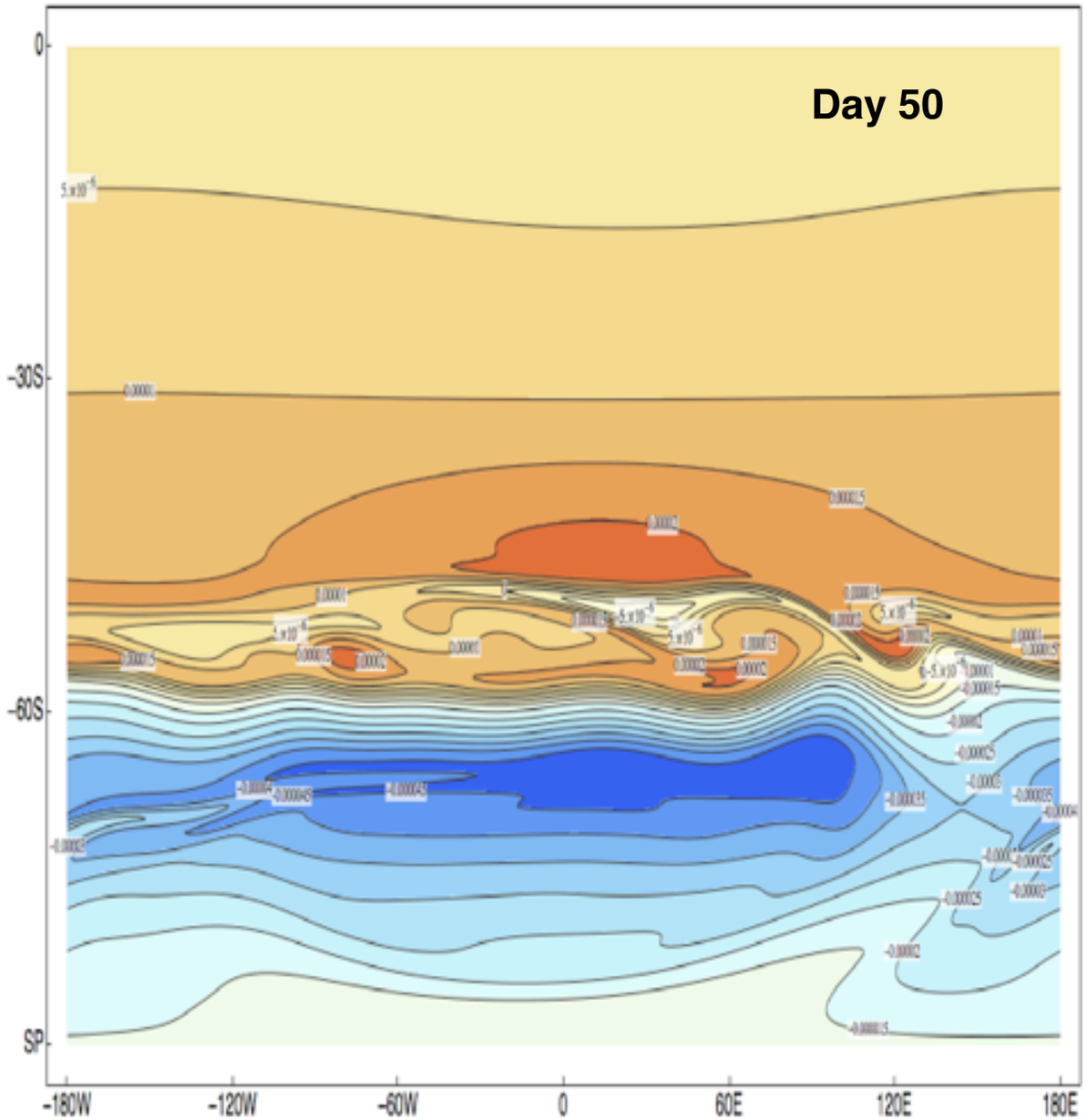
Relative vorticity in a RWB episode (Day 40)



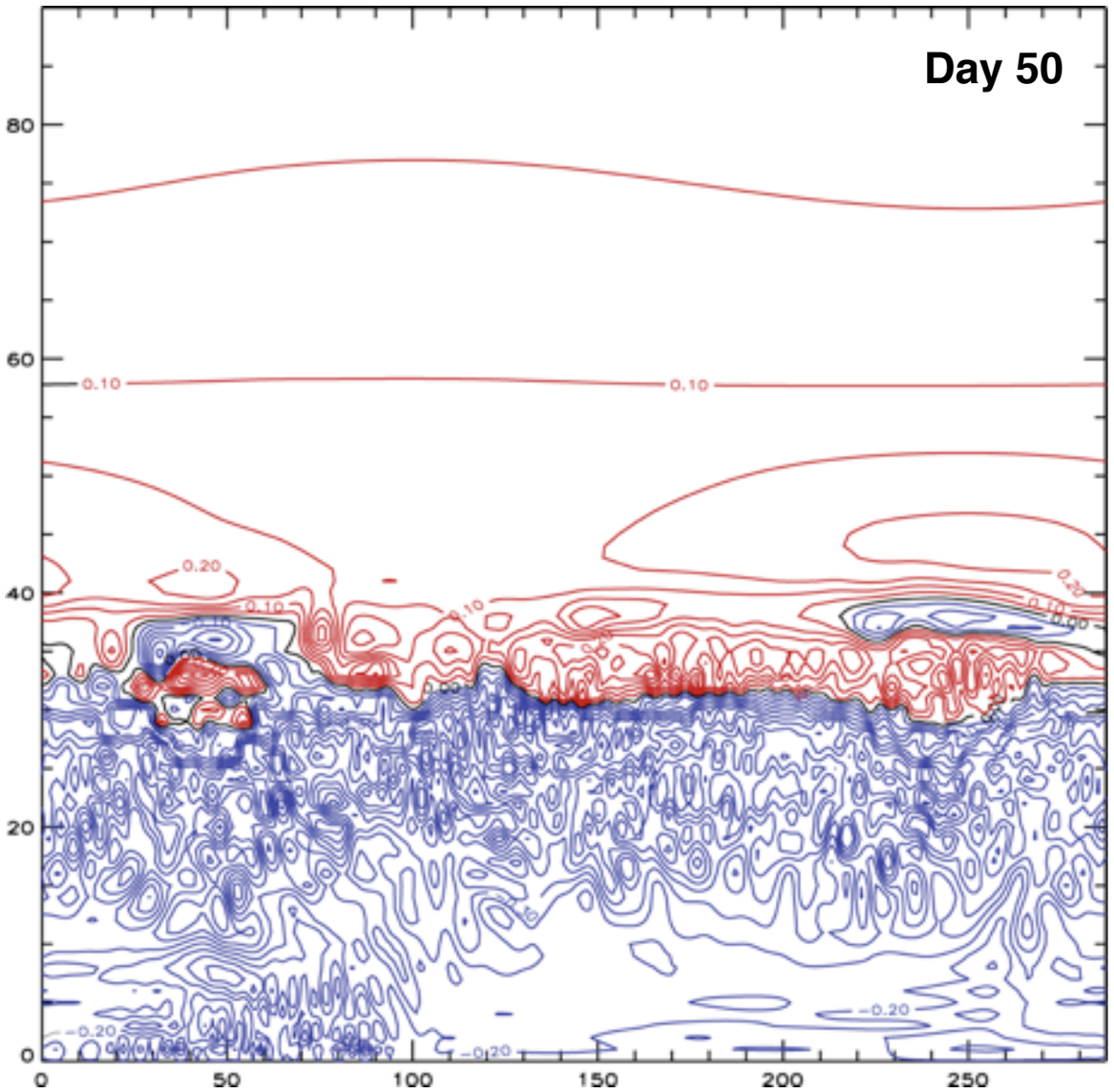
Lon-Lat model resolution: 1^{o}X1.25^{o} (grid distance is approx. 100 km)
Time step: 2 secs

Relative vorticity in an RWB episode (Day 50)

Icosahedral model



Lon-Lat model (with second-order SAH scheme)

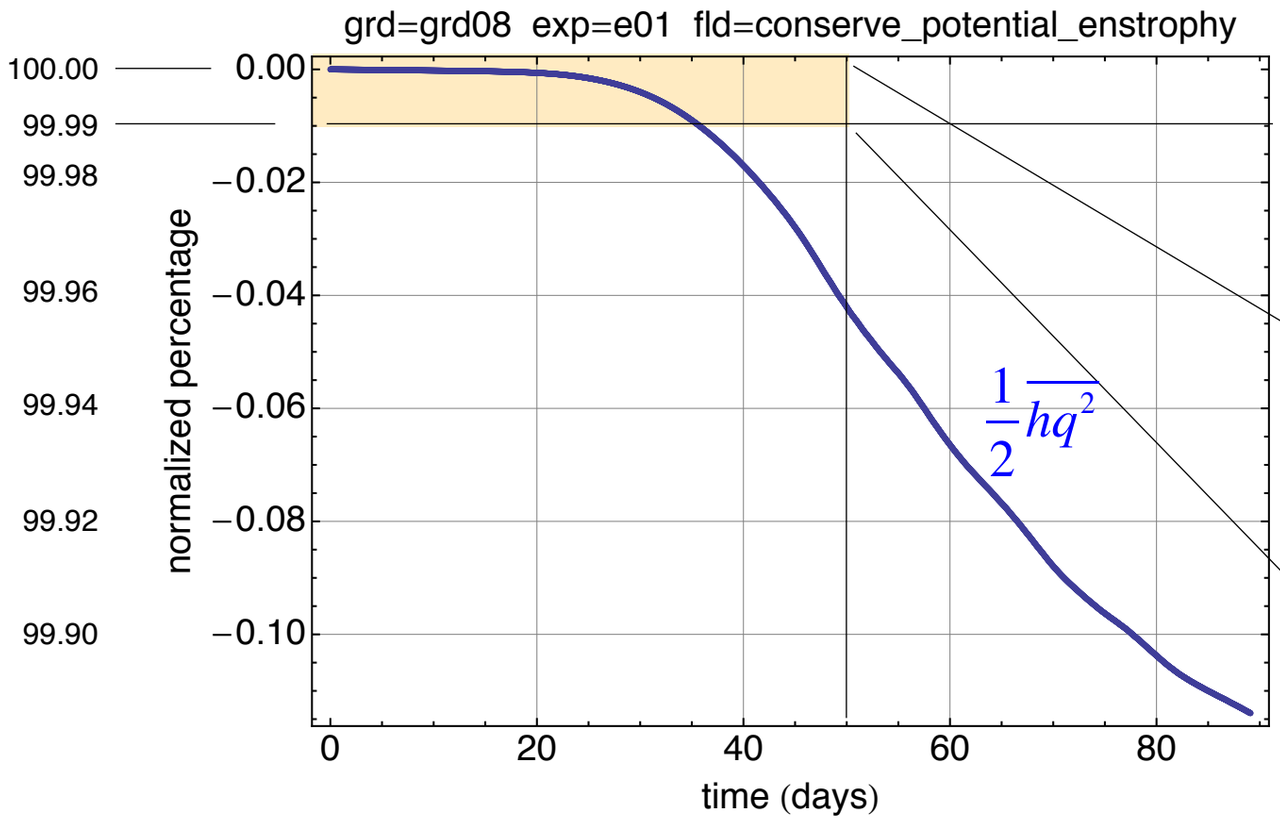


Icosahedral model resolution: G8 (grid distance is approx. 30 km)

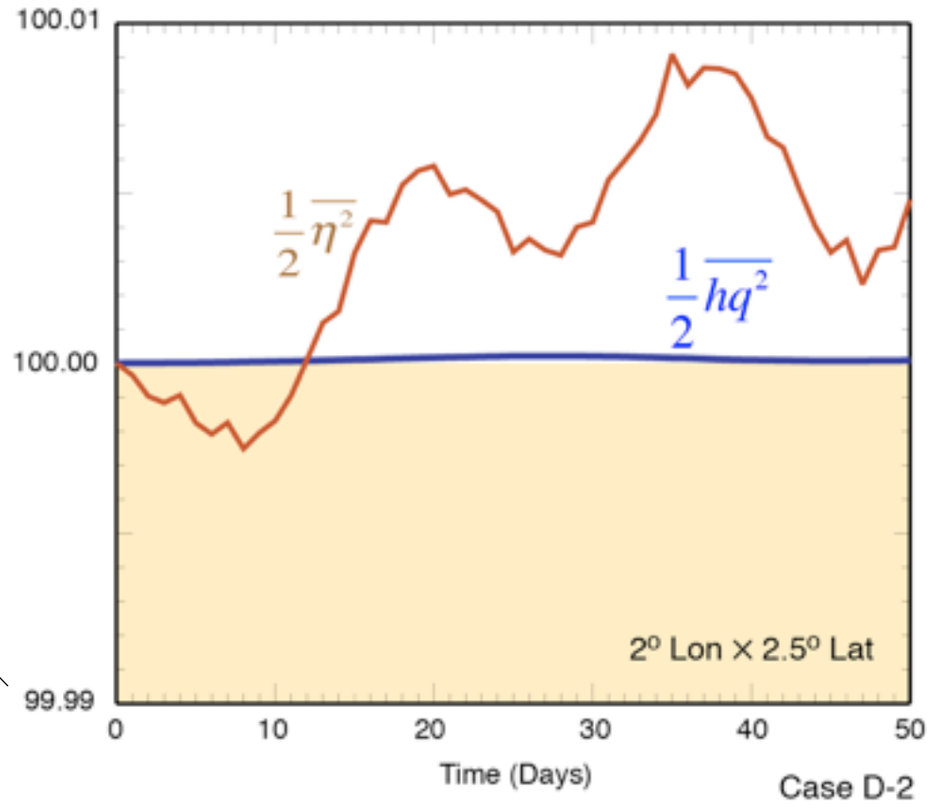
Lon-Lat model resolution: 1°X1.25° (grid distance is approx. 100 km)
Time step: 2 secs

Potential enstrophy

Icosahedral Model



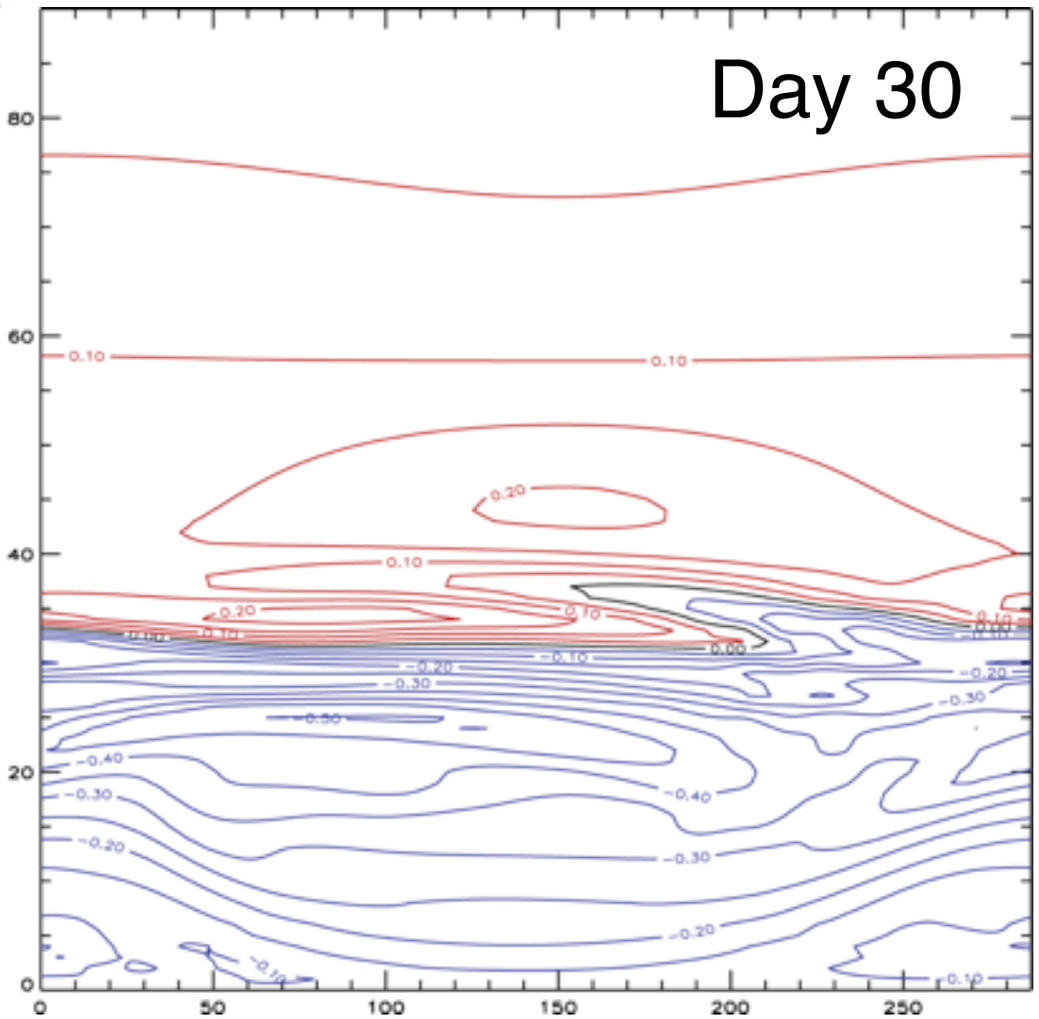
Lon-Lat Model (second-order SAH scheme)

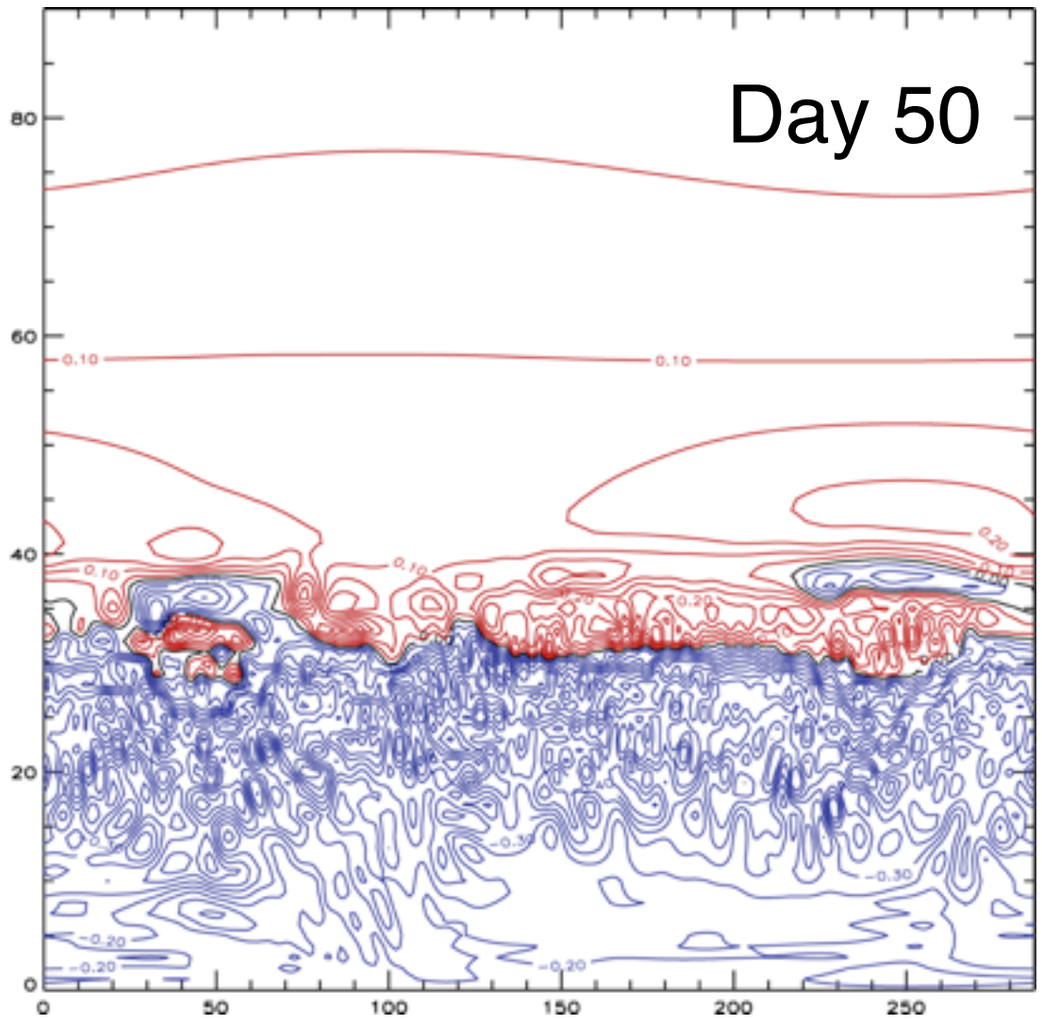


Relative vorticity in an RWB episode

Lon-Lat model (with second-order AL scheme)

EQ





EQ

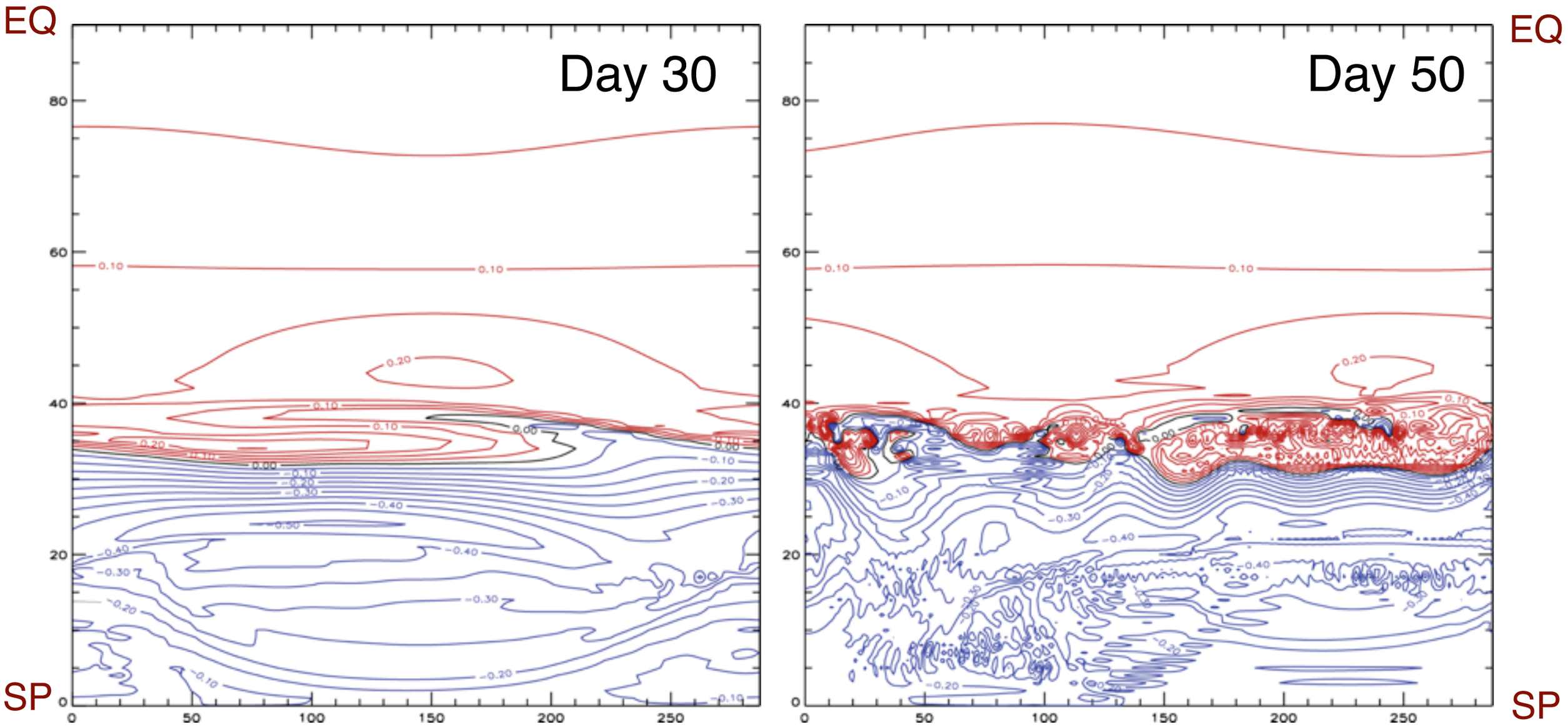
SP

SP

Lon-Lat model resolution: 1^{o}X1.25^{o} (grid distance is approx. 100 km)
Time step: 2 secs

Relative vorticity in an RWB episode

Lon-Lat model (with fourth-order ST scheme)

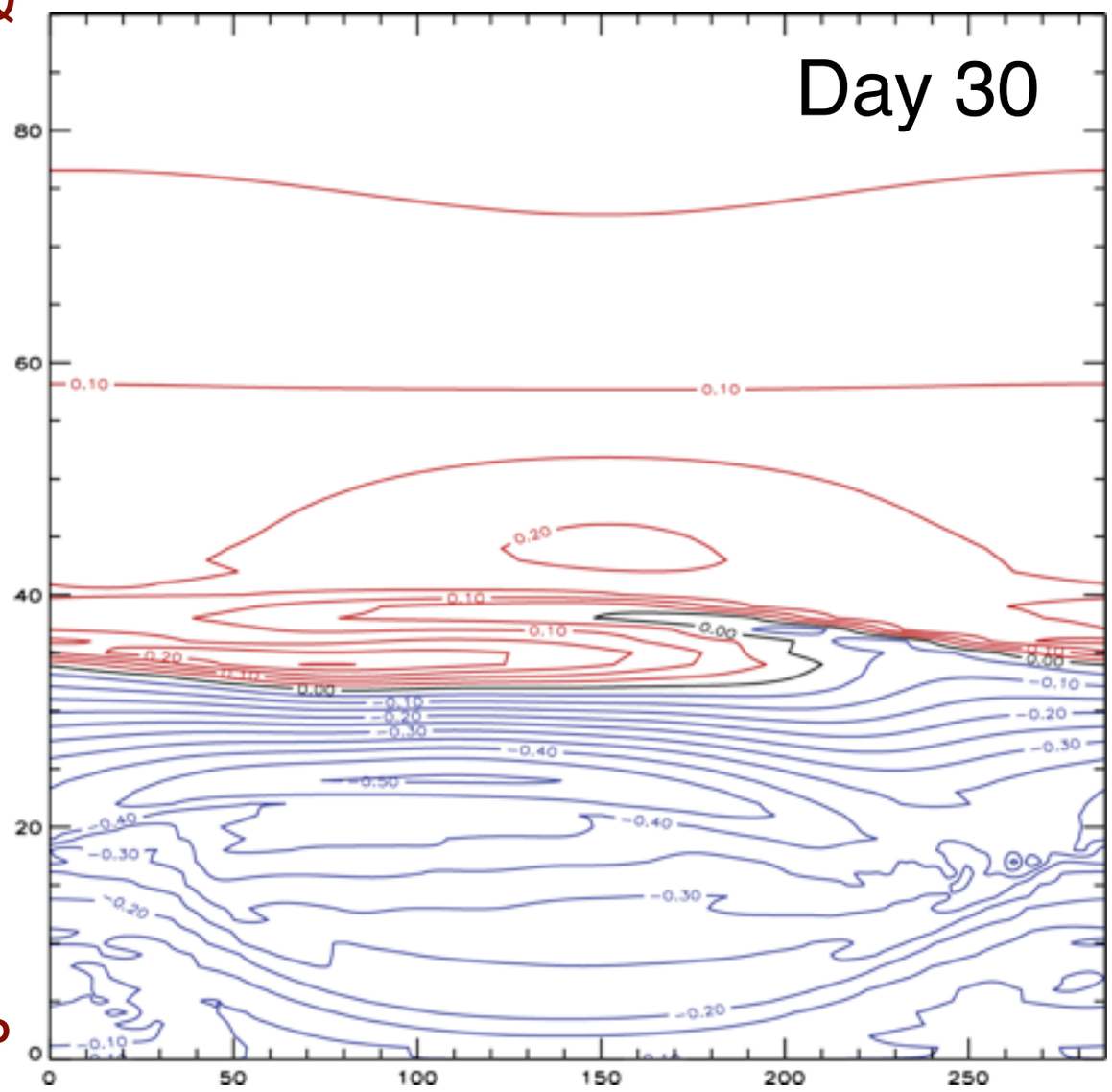


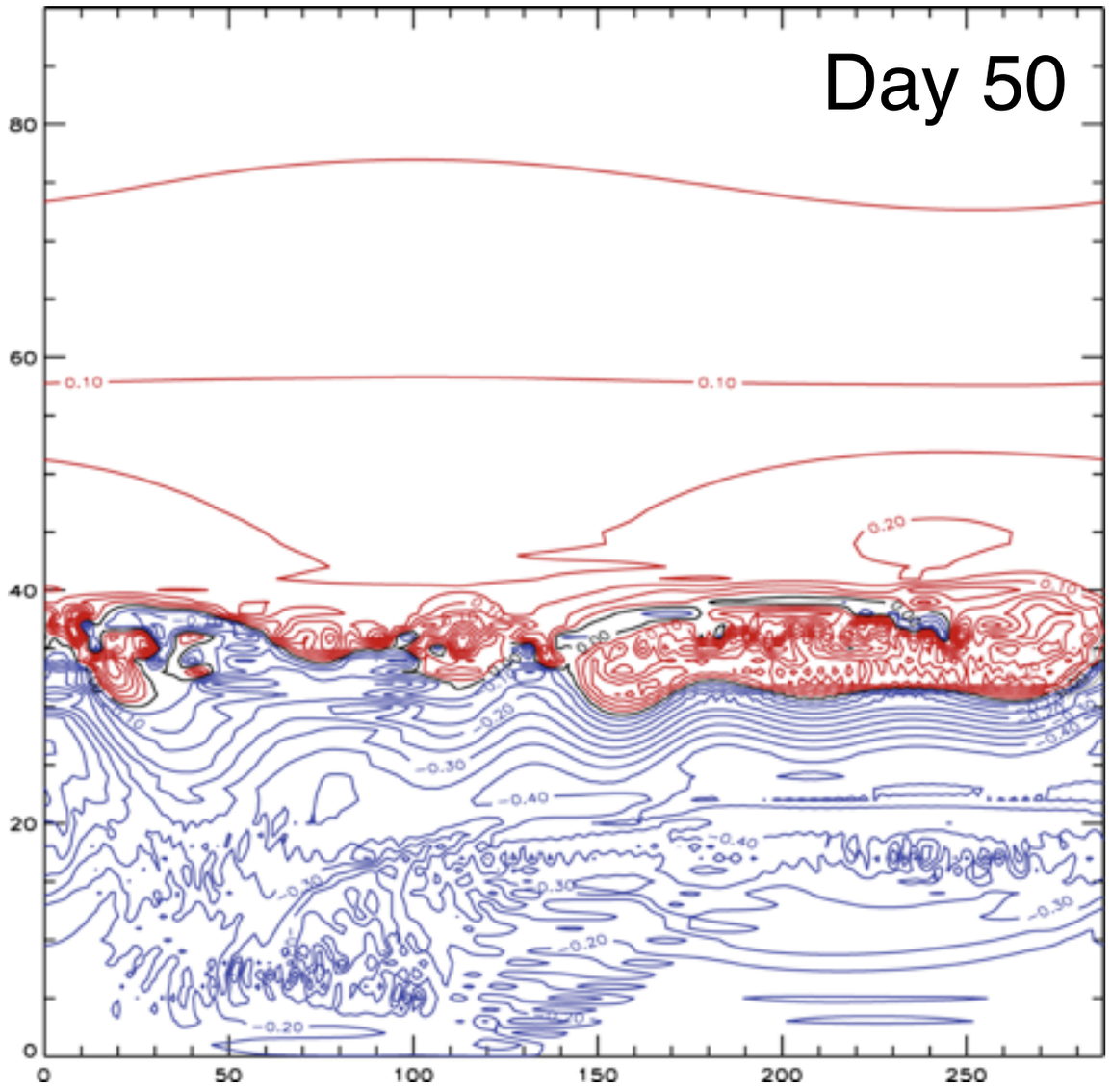
Lon-Lat model resolution: 1^{o}X1.25^{o} (grid distance is approx. 100 km)
Time step: 2 secs

Relative vorticity in an RWB episode

Lon-Lat model (with fourth-order TW scheme)

EQ





EQ

SP

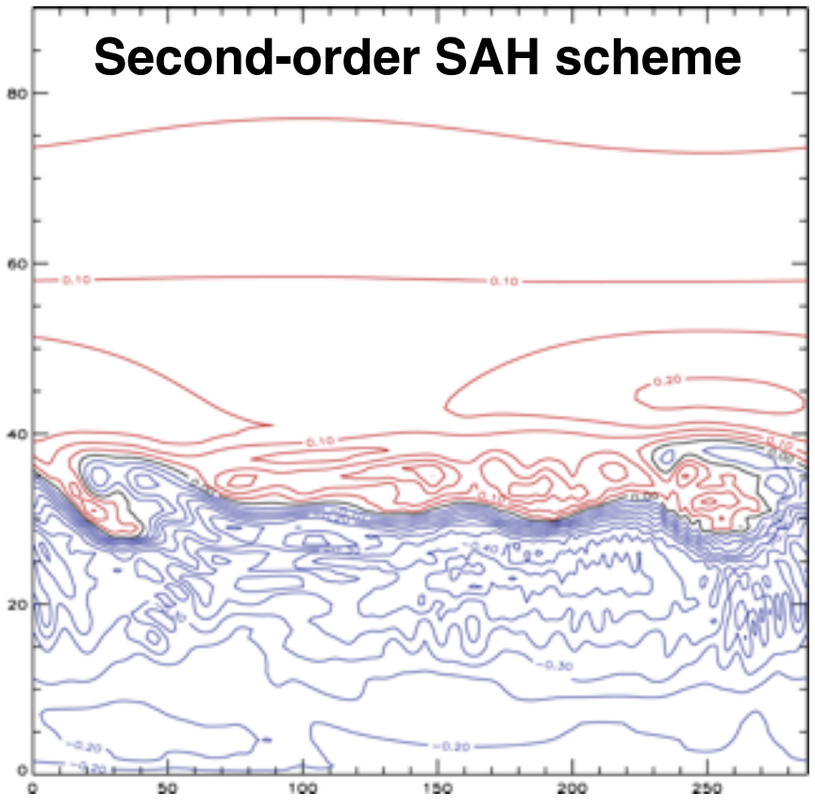
SP

Lon-Lat model resolution: 1^{o}X1.25^{o} (grid distance is approx. 100 km)
Time step: 2 secs

Relative vorticity in an RWB episode (Day 50)

With second-order diffusion of velocity

EQ



SP

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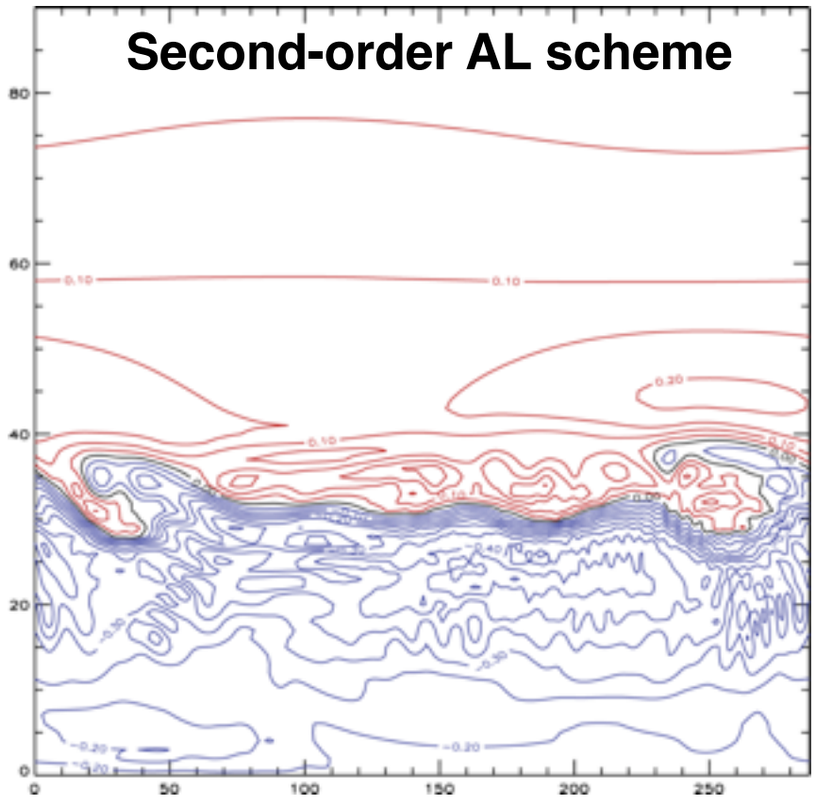
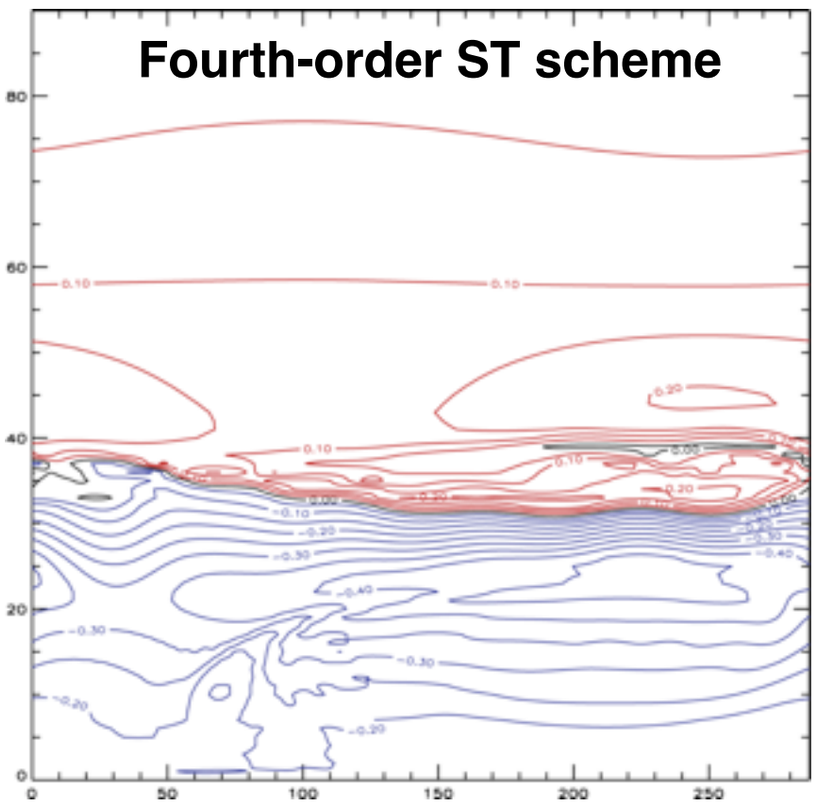


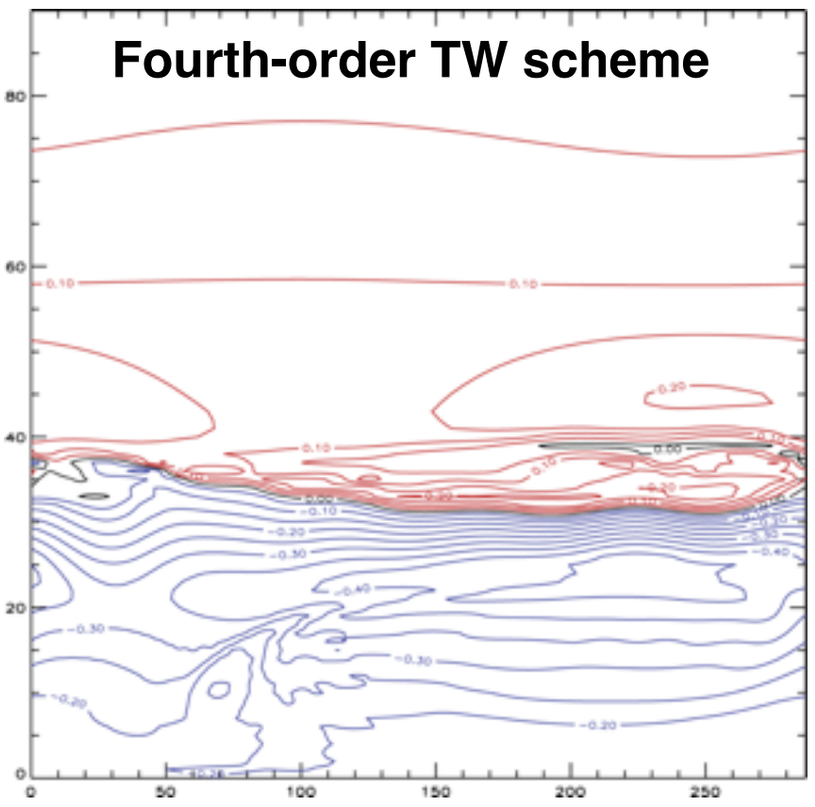
SP

EQ



SP

EQ



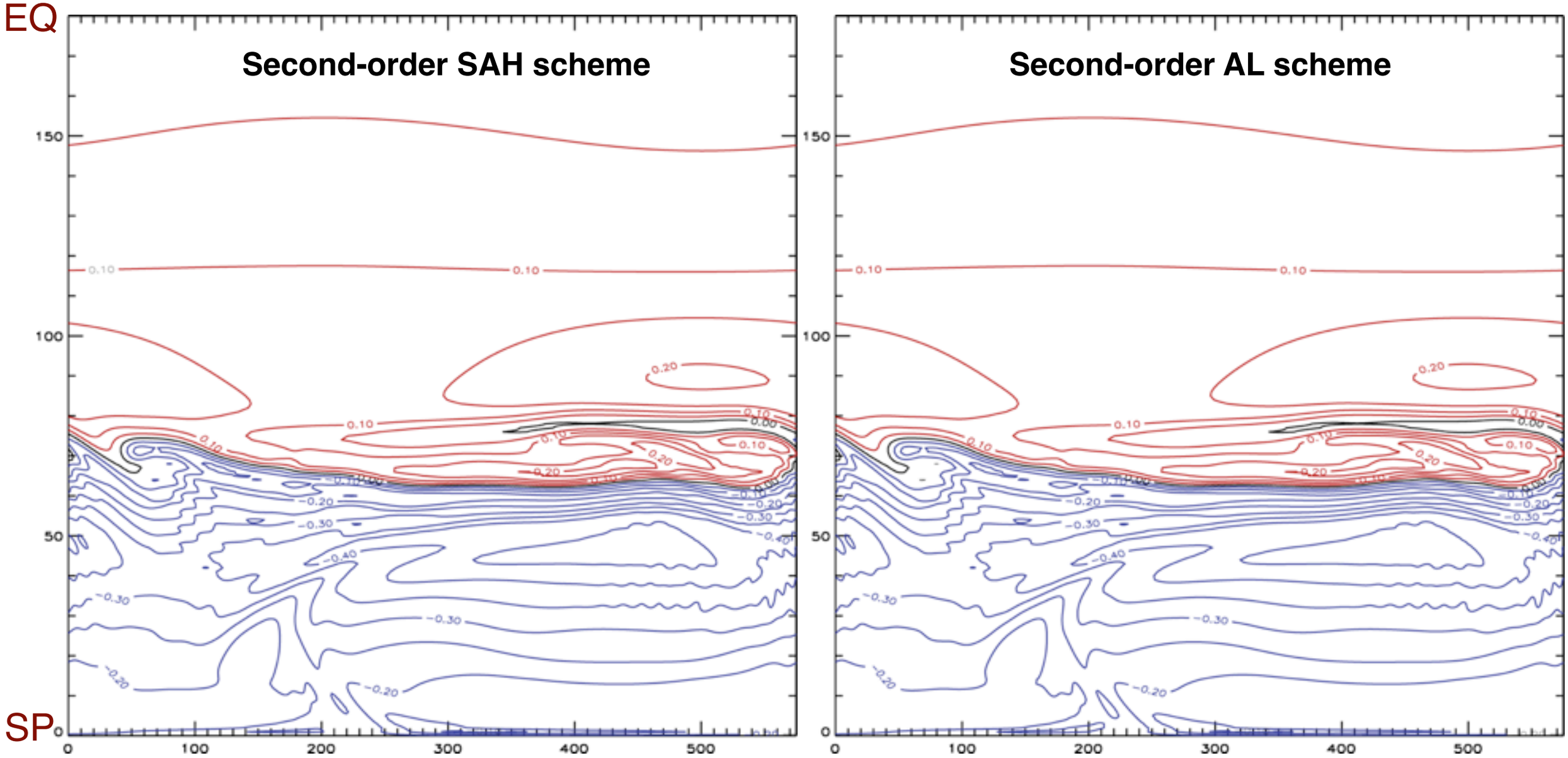
SP

Lon-Lat model resolution: 1°X1.25° (grid distance is approx. 100 km); Time step: 2 secs Coeff.=0.25m²/sec

Relative vorticity in an RWB episode (Day 50)

Lon-Lat model

With second-order diffusion of velocity



Lon-Lat model resolution: $0.5^{o}X0.625^{o}$
(grid distance is approx. 50 km)
Time step: 1 secs

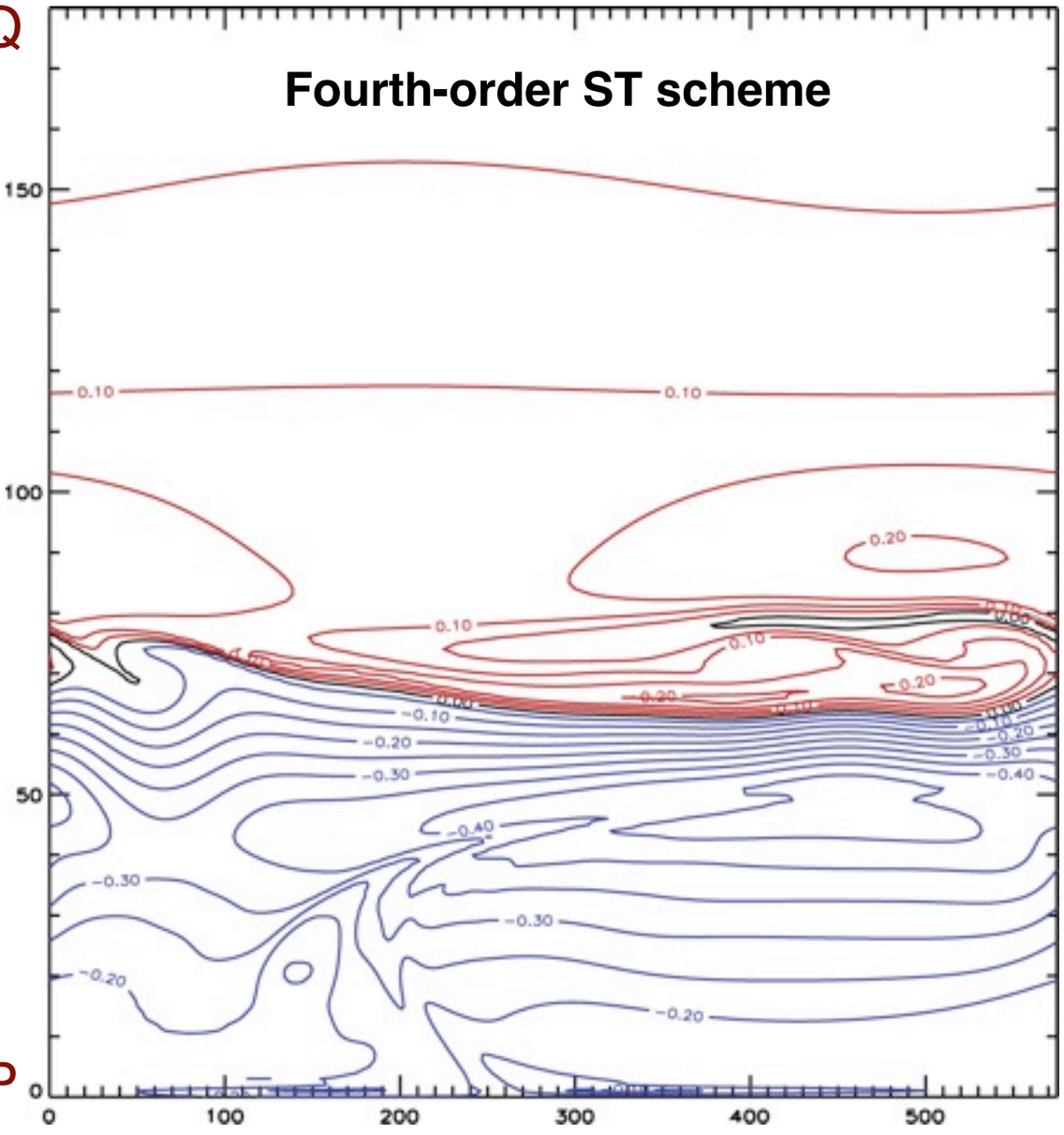
Coeff.=$0.25m^2/sec$

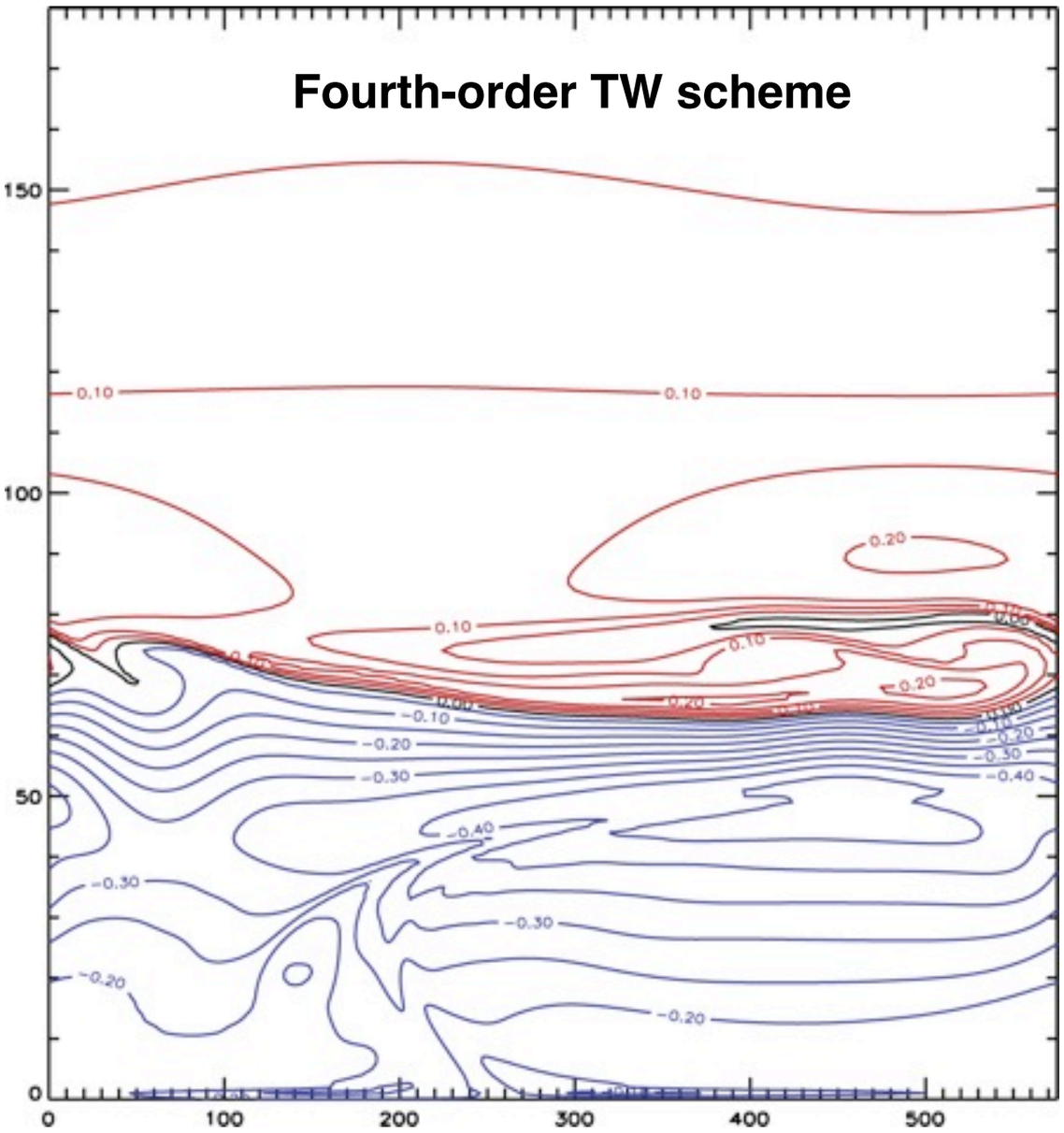
Relative vorticity in an RWB episode (Day 50)

Lon-Lat model

With second-order diffusion of velocity

EQ





EQ

SP

SP

Lon-Lat model resolution: 0.5°X0.625°
(grid distance is approx. 50 km)
Time step: 1 secs

Coeff.=0.25m^2/sec

Comparison of results

- There are differences between the simulations of the late stages of RWB with the Icosahedral and Lon-Lat models.
- Lon-Lat model produces noise while conserving potential enstrophy.
- Icosahedral model does *not* produce noticeable noise. It dissipates potential enstrophy.
- Switching to the high-order schemes and/or adding diffusion reduce noise in Lon-Lat model simulations.
- Simulated phase speed remains different between icosahedral and lon-lat solutions.

Integration of barotropic vorticity equation (Barotropic Model)

$$\frac{\partial \eta}{\partial t} = -\nabla \cdot \left(\eta \mathbf{v}_\psi \right) \qquad \eta \equiv \zeta + f$$

$$\mathbf{v}_\psi = \mathbf{k} \times \nabla \psi \qquad \nabla^2 \psi = \zeta$$

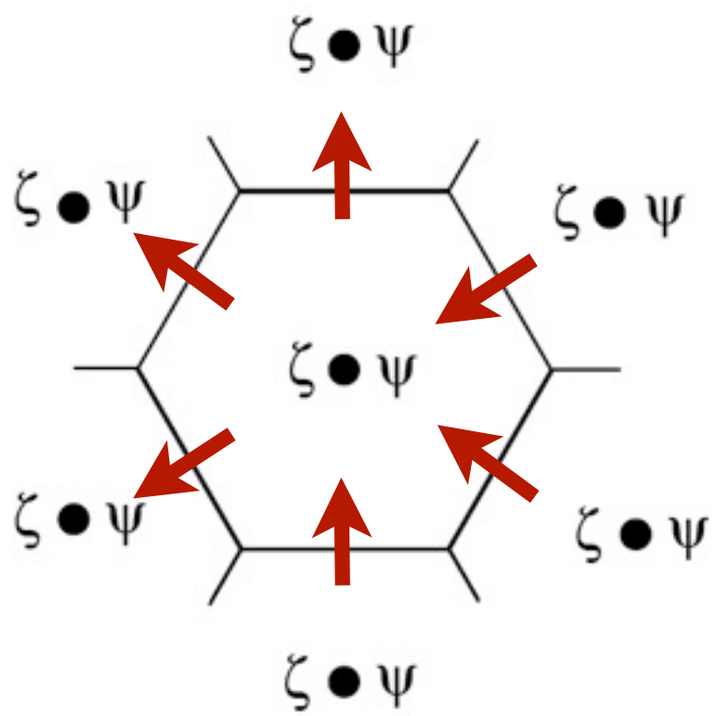
1) Icosahedral barotropic model

- Barotropic version of CSU's global icosahedral grid model

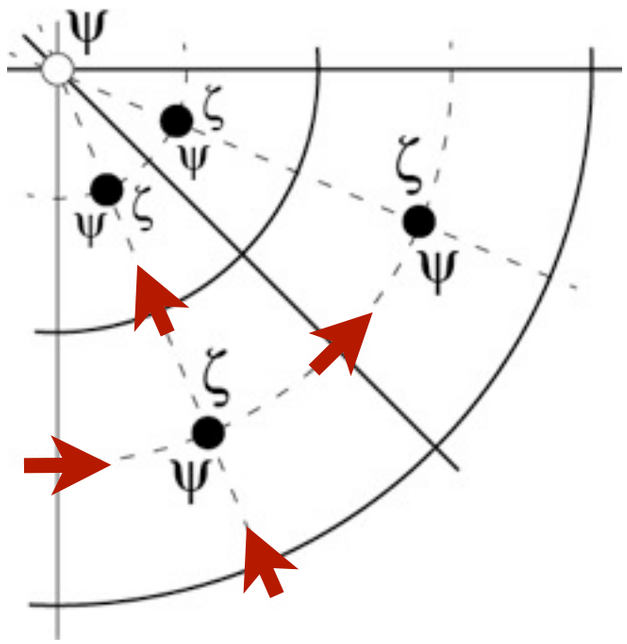
2) Lon-Lat barotropic model

- Barotropic model version of a new Lon-Lat Z-grid shallow-water model
- It is not based on Arakawa Jacobian

Icosahedral Z-grid

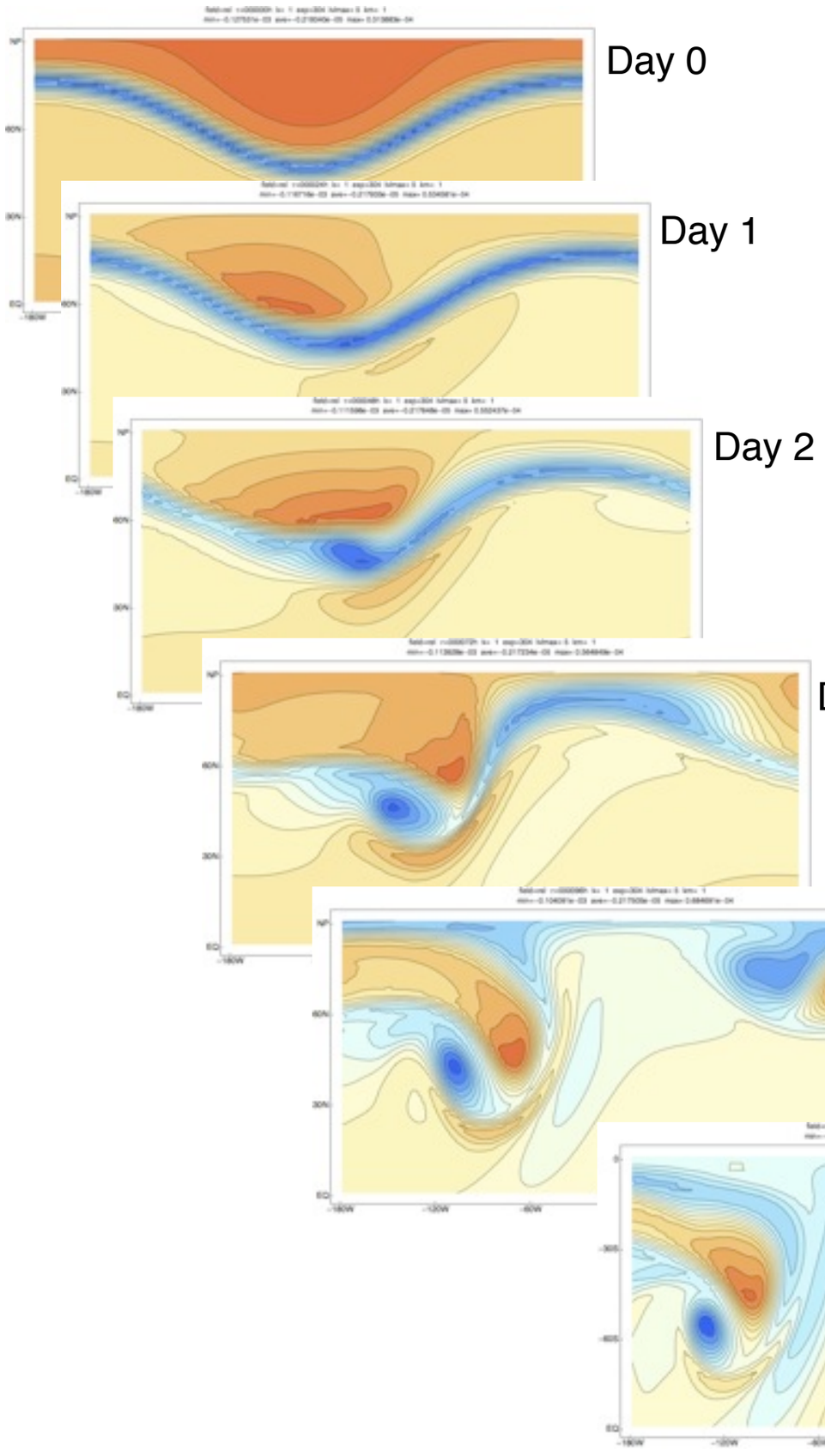


Lon-lat (Cartesian) Z-grid

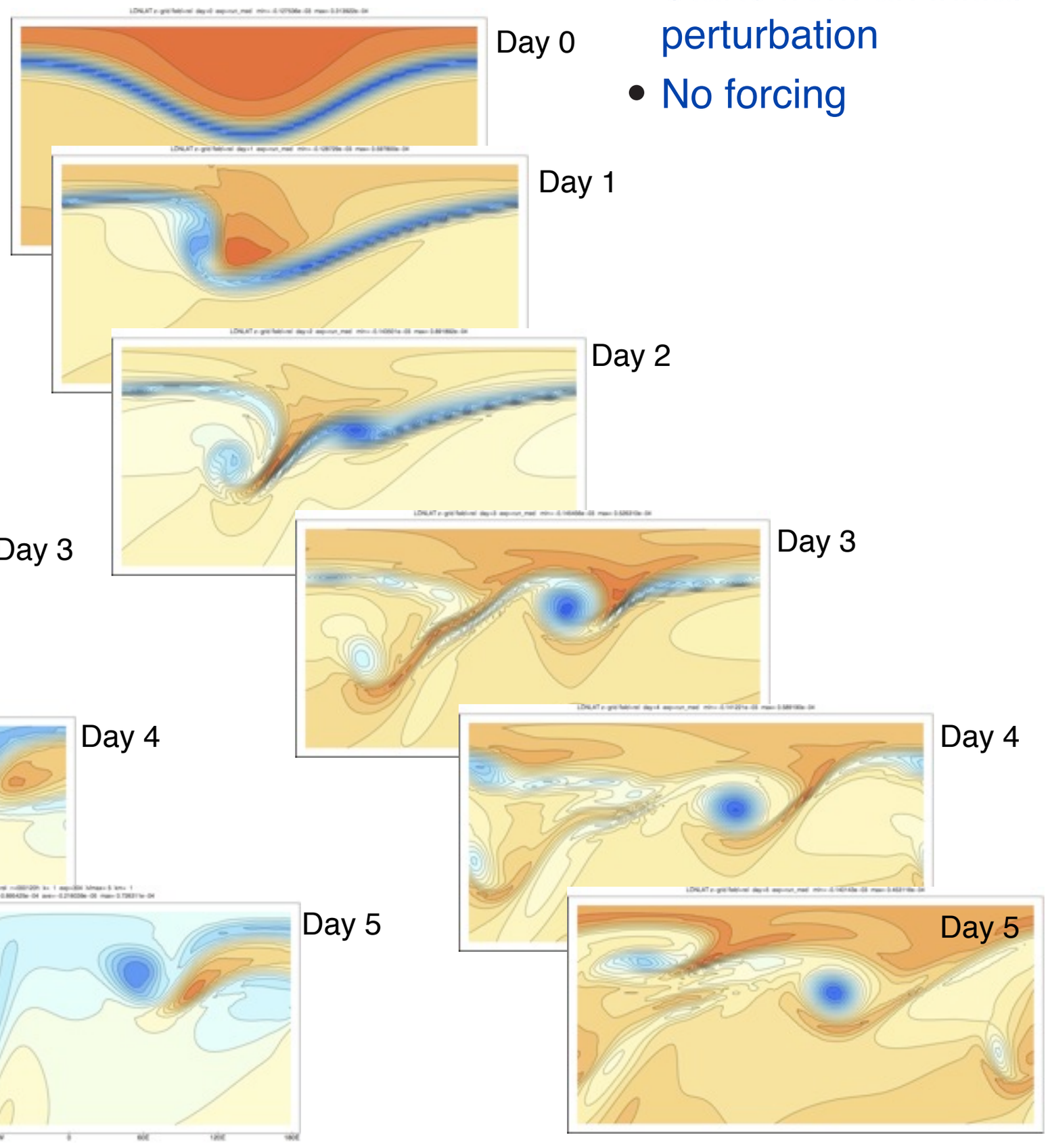


Integration of barotropic vorticity equation (Barotropic model)

Icosahedral G5 (~240 km)



Lon-Lat (Cartesian) $2^{o}X2.5^{o}$

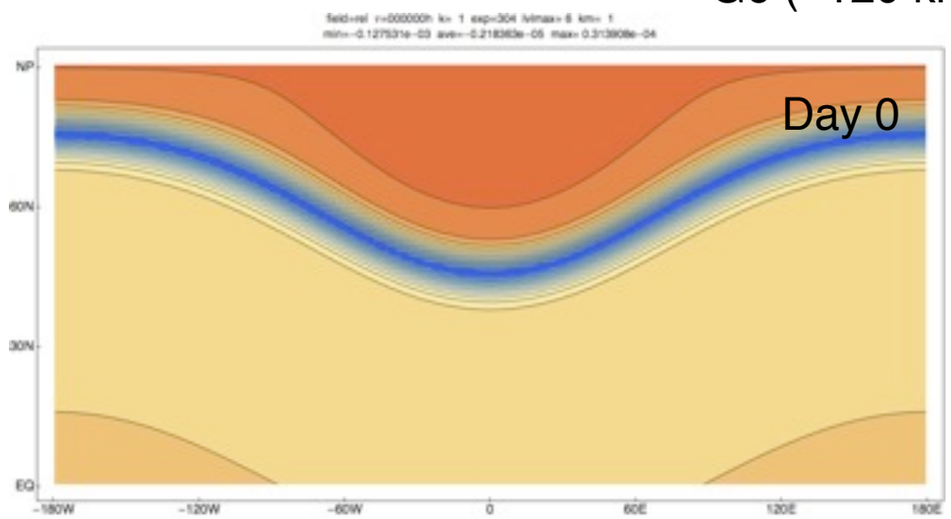


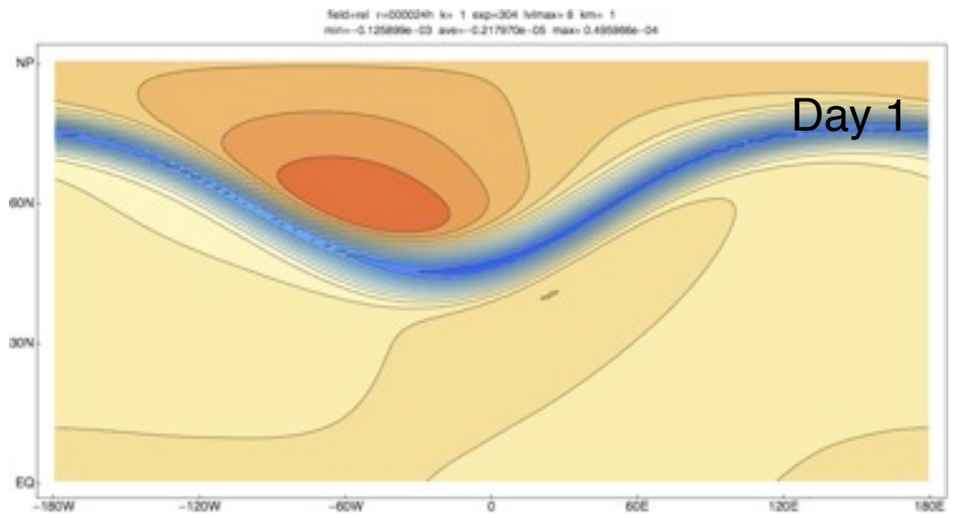
- Starts from an initial perturbation
- No forcing

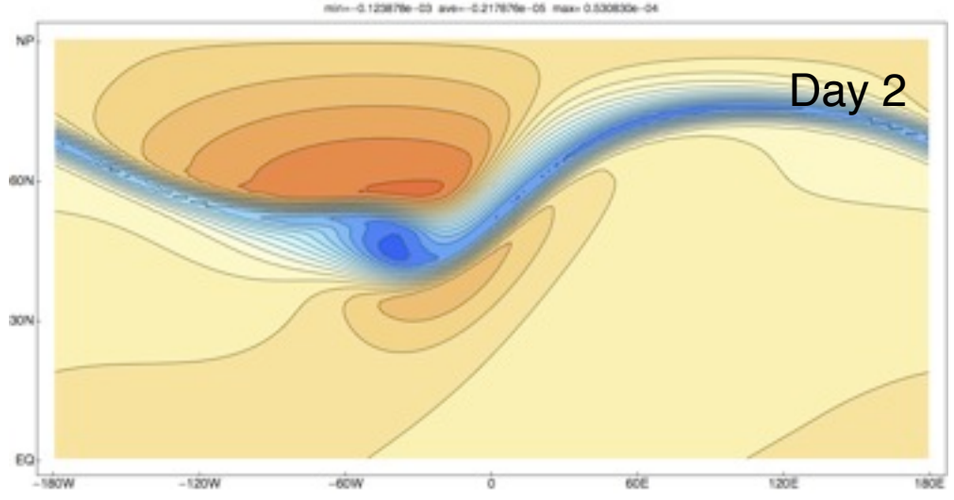
Integration of barotropic vorticity equation (Barotropic Model)

Icosahedral

G6 (~120 km)

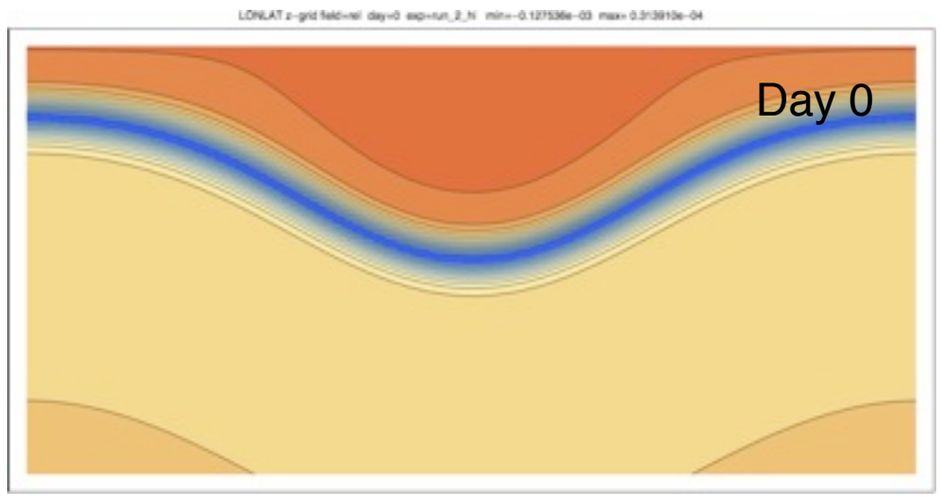


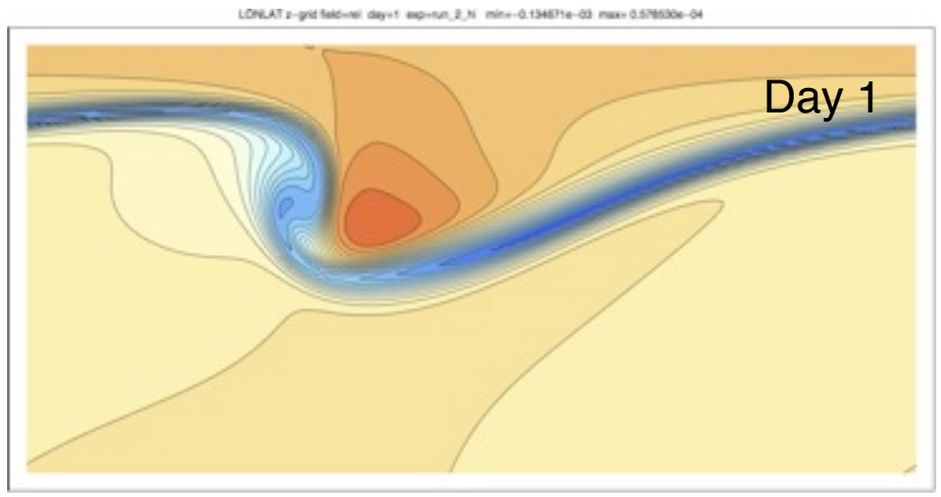


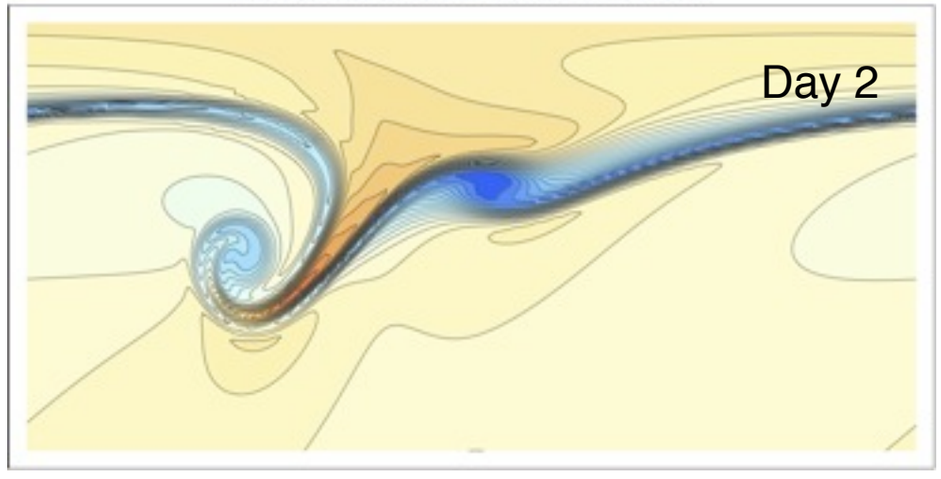


Lon-Lat (Cartesian)

1°X1.25°







Question

- Where do these differences coming from?